Wisconsin Highway Research Program

Integrated Field and Office Tools for Bridge Management

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16. Abstract

WisDOT's Bureau of Structures data consolidation project brings together all bridge-related data into a single Highway Structure Inventory System (HSIS) data warehouse including inventory, inspection and maintenance records, and maintenance cost. With the new HSIS, WisDOT's interactive bridge inspection forms and data procedures became incompatible. The HSIS presented a timely opportunity to investigate alternative data collection tools that are practicable in the field. This research investigates the use of field data tools for bridge inspection. Bridge inspectors participated in identifying functional requirements leading to an assembly of field tools including Tablet PC with shoulder carrying case, noise-canceling headset microphone, and tethered pen. Bridge inspectors from 6 districts volunteered for training to use the handwriting and speech recognition technologies and then to test the tools for practical use in bridge inspection. This report presents the tool selection process, training, and evaluation of technology adoption and economic benefits. The report includes an evaluation of alternative technologies choices along with recommendation for full deployment.

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Executive Summary

Project Summary

This research investigates the use of field data tools for bridge inspection. Bridge inspectors participated in identifying functional requirements leading to an assembly of field tools including Tablet PC with shoulder carrying case, noise-canceling headset microphone, and tethered pen. Bridge inspectors from 6 districts volunteered for training to use the handwriting and speech recognition technologies and then to test the Tablet PC tools for practical using in bridge inspection. Eight field tool assemblies were purchased and permanently distributed to the 6 participating districts and the Central Office. The Research Team prepared a database for hyper-linking the bridge inspector's pocket manual to the HSIS routine bridge inspection form.

Background

WisDOT's Bureau of Structures data consolidation project brings together all bridge-related data into a single Highway Structure Inventory System (HSIS) data warehouse including inventory, inspection and maintenance records, and maintenance cost. With the new HSIS, WisDOT's interactive bridge inspection forms and data procedures became incompatible due to software and database design changes. The HSIS presented a timely opportunity to investigate alternative data collection tools that are practicable in the field.

The Department of Civil and Environmental Engineering at University of Wisconsin-Madison through the Wisconsin Highway Research Program conducted the project. The Research Team included Teresa M. Adams (Professor and Principal Investigator), Emil Juni, Mohsin Siddiqui, and James Dzienkowski (Graduate Students) and David Babler (WisDOT Bridge Engineer). A number of other WisDOT bridge engineers and inspectors participated in the research including Scot Becker, Allen Bjorklund, Shiv Gupta, Greg Haig, Tom Hardinger, Dan Harrington, Patrick Kern, Travis McDaniel, Jim McDowell, Matthew Murphy, Jim Oettinger, Steve Severson, Dale Weber, and Stanley Woods.

Process

This research methodology is based on a technology implementation model for reducing resistance to technological change. The process for conducting the research included the following features:

- Bridge inspectors participated in the technology selection process.
- Bridge inspectors volunteered to participate in the testing and evaluation.
- Training was conducted one-on-one, at the districts, and included using the Tablet PC in the field for real-world bridge inspection.
- After training, the Research Team contacted the participating Bridge Inspectors on a weekly basis to identify barriers to implementation, assist with technology problems, and get feedback.
- Inspectors provided data on use and technology adoption through a weekly questionnaire.
- The Research Team assessed the economic impacts of the field tool technology adoption and provided recommendations for institutionalization.

The technology options considered for the field tool include PDAs, Tablet PCs, and Wearable PCs. Requirements considered include the desire to minimize software development and subsequent maintenance, and the desire to provide consistent look and feel to the end-user in the field and the office. The project involved a literature survey regarding the use of information technologies for field data collection and bridge inspection, and an evaluation of alternative technologies choices.

The research was conducted over a period of 15 months beginning in September 2002. Bridge inspectors at WisDOT Districts 1, 3, 4, 5, 6, and 8 and WisDOT Central Office were trained and the field tool was tested during late spring, summer and early fall of 2003. Research results were formally presented at the Fall Statewide Structure Maintenance Meeting in November 2003.

Findings and Conclusions

The overall finding is that the Tablet PC is a viable and adoptable tool for collecting bridge inspection data in the field. The benefits from time savings will outweigh the cost of purchasing the equipment. (Software costs are negligible because WisDOT's data management tools being developed for office use can be taken to the field without modification.) Time savings is attributed to eliminating the need to transcribe inspection data from paper forms to a computerized database. Payback analysis shows considering time savings alone, each Tablet PC would pay for itself in 0.8 to 1.33 years or after 120 to 200 bridges are inspected.

Other benefits include potentially more detailed and accurate inspection data. Data capture at the bridge site using convenient handwriting or speech recognition tools may lead to more detailed inspection notes and reduce the possibility of transcribing ambiguously inspection notes. Having the Inspector's Pocket Manual hyperlinked to the Electronic Inspection Form, makes referencing the Pocket Manual very convenient. This may lead to more use of the pocket manual and more consistent inspection reports.

The participating inspectors tried both speech recognition and handwriting recognition technologies. Inspectors were able to adopt handwriting recognition technology much more successfully than speech recognition technology. The speech recognition technology was found to be unacceptable for several reasons. First, implementation of speech recognition technology requires upfront time and continued effort to create a robust speech profile. Second, inspectors must speak at a constant rate and concentrate on enunciating clearly so that words are correctly recognized. Third, like learning to dictate a letter, inspectors must compose and dictate complete sentences on the fly. Finally, despite the use of high quality, noise-canceling microphones, background noise from highway traffic interfered with results causing inspectors to frequently edit results. Speech recognition technology may improve in the future, but the handwriting recognition worked so much more efficiently and was accepted very well.

The success of this research project was limited by institutional barriers that made it difficult for inspectors to use the technology. Bridge inspectors encountered several frustrations that influenced their willingness and ability to test the Tablet PC technology. First, the inspectors were not allowed to connect the Tablet PCs to the WisDOT computing network infrastructure or given basic technical support such licenses for virus protection

software. Second, the typical software bugs and business process changes associated with deploying the new HSIS Electronic Inspection Form were reflected in the inspectors' reluctance to use the Tablet PC Field Tool. Inspectors were frustrated with the limitations of the new Check-in/Check-out process for retrieving and reporting inspection records. This frustration was evident in their reluctance to participate in the Tablet PC evaluation project.

Inspectors, who made an effort, were able to adopt the handwriting technology and are enthusiastic about streamlining and improving their work process. Removing the institutional barriers will enable less enthusiastic inspectors to easily adopt the technology.

Recommendations for Further Action

The research findings support full deployment of the Tablet PCs to the districts as replacement for retiring notebook computers and field inspection tools. The Tablet PC can be used in the field or office. In reviewing the technology choices for the field tool configuration, a few features are essential for full deployment. It is also important to emphasize the particularly positive features of the tested tool; that is, what not to change.

"Convertible" Tablet PC is a good choice. The Tablet PC with a shoulder strap and carrying case gives inspectors a paper-and-clipboard ability to enter data while standing at the bridge site using handwriting and speech recognition tools. Individual inspectors will likely develop a preference for handwriting or speech recognition; both require some effort to adopt. The use of convertible-type Tablet PC is preferred over a slate-type, because it can also function as a notebook PC in the office or field. Furthermore, when possible, some inspectors do prefer to use the mechanical keyboard attached to a convertible Tablet PC.

Electro Magnetic Resonance (EMR) (active digitizer) is a good choice. The alternative, Pressure Sensitive (passive digitizer) input for handwriting recognition requires much heavier pressure than for normal writing on paper. Inspectors will be much more successful in adopting handwriting recognition technology with EMR digitizer.

Alternative LCD technology choices should be re-evaluated at the time of purchase. The best choice is screen technology designed for outdoor viewing, but also readable in the office lighting. Given current technology choice for LCD screens "Treated Transmissive" screens offer the best compromise for indoor and outdoor viewing. The Research Team applied Anti-reflective (AR) films to the outside of the LCD screens as a treatment, with only minor effects. Factory treated LCD panels may work better.

The Tablet PC training that was provided to the inspectors was well received. Successful implementation of the research results is dependent upon a formal training phase. **Inspectors need training on how to use and customize the handwriting and speech recognition tools.** The training materials included with this report can assist the agency with training.

Chapter 1 Introduction

Statement of the Problem

The WisDOT Bureau of Structures' data consolidation project brings together all bridge-related data into a single data warehouse called the Highway Structures Information System (HSIS). Bridge-related data include inventory, inspection and maintenance records, and maintenance costs.

The software platform for the HSIS is Oracle DBMS. Districts and counties are database clients while the Central Office maintains the database server. The State's bridge management system (Pontis) at the Central Office retrieves data from the HSIS for preservation analysis and functional improvement programming.

As a result of the data consolidation project, WisDOT's existing field data collection tools for bridge inspectors became obsolete. WisDOT needed to reprogram the electronic screen forms to be compatible with the new Oracle database server. WisDOT developed database forms for submitting bridge inspection and inventory data to the HSIS via the Internet. The full screen Internet forms work well for office procedures but are inconvenient for field use.

The data consolidation project presents a timely opportunity to develop modern data collection tools to be far more practical in the field. From past experience, notebook computers as field data collection tools for bridge inspectors are impractical at the inspection site. Until new tools are developed, inspectors will need to complete paper copies of the inspection forms in the field and then transcribe information to the HSIS Internet forms.

Project Motivation, Goal and Objectives

This project was motivated by the WisDOT Bureau of Structures' desire to take advantages of new human-computer interface technologies to improve the performance of field bridge inspection. Specifically, the goal of the project was to investigate technologies that would allow bridge inspectors to take the newly created web-based inspection forms to the field for data collection at the bridge site.

To accomplish the project goal, the following objectives were achieved:

- Configure a user-friendly field inspection tool that fits with the existing inspection process
- Test and evaluate the tool, and
- Evaluate benefits of the field tool, and
- Recommend an implementation strategy.

Data Process for Bridge Inspection

Prior to the HSIS, WisDOT distributed subsets of the full bridge inspection database along with an electronic inspection form interface to the database. Inspectors could take a notebook computer loaded with the District's bridge database and inspection form interface to the field where they could update the inspections data at the bridge site. Bridge inspectors found the notebook computers as field data collection tools to be impractical at the inspection

site. Inspectors report safety concerns and awkwardness while carrying the notebook computer when walking or climbing the bridge structure. Furthermore, finding a convenient and stable arrangement for keyboard data entry was always a challenge. Table 1-1 summarized the field data collection process prior to the HSIS and this research. At best, inspectors found ways to use their notebook computers in their vehicles. Most inspectors simply printed paper copies of the inspection form, completed the paper form at the bridge site, and then at their office, transcribed the inspection data into the district database. The district database was then sent to the central office (via file transfer) where it was used to update the statewide database.

Table 1-1. Inspector's data process and productivity prior to the HSIS

			Average per Bridge		
Inspector	Data Entry Location	Bridges Inspected per Week	Pocket Manual References	Field Inspection (min.)	Data Entry (min.)
1	Office	15	4	60	15
2	Office	3	1	20	10
3	Office	30	5	15	10
4	Office	30	4	45	5
5	Office	25	1	50	8
6	Office/Vehicle	10	1	20	10
Average		19	3	35	10
Standard deviation		11.2	1.9	19.0	3.3

Literature Review

Field Data Collection Tools at Other State Transportation Agencies

Information technologies for managing field data collection increase the reliability of inspections and the productivity of inspectors (Fortner 2000). New technology is offering capabilities that have not been previously available ("Computer" 2001). New computer technologies are being used by inspectors to fill out the inspection form, access previous inspection reports, make sketches of the bridge elements, store photographs, and produce the inspection report while in the field. The use of an automated inspection system simplifies the data processing effort, improves inspection data accuracy, and permits bridge inspectors to devote more time to the actual inspection process (Elzarka 1999).

Table 1-2 summarizes the findings of a literature review regarding the use of information technology to support bridge inspection data collection. Enabling technologies, such as handheld and pen based computers can improve field inspection (Thierrin 1999). Notebook PCs, Personal Digital Assistants (PDAs), Wearable PCs, and Tablet PCs are examples of the equipment used to perform inspection. Pen-based technology has been used at the South Carolina DOT with success. PDAs are used to input inspection data as opposed to paper forms. Tablet PC mobility, ease of use, and built-in wireless connectivity are enabling information workers to use their PCs in the field and office (Microsoft 2002). Voice and handwriting recognition capabilities are not always reliable.

The inspection process can take inspectors to irregular and unstable terrain where hands free movement is required. Pennsylvania experimented with a wearable computer that allows hands free operation for data input and retrieval (Garrett 1998). Wearable computers are specially configured and programmed for applications such as bridge inspection; as such cannot be used for other general computing applications. Furthermore, the high cost of wearable computers could be a substantial deterrent (Nobel 2000) and inspectors may need to overcome a bias against wearable computers because of the strange look and feel that accompany the unit.

Table 1-2. Applications of information technology to support field data collection

Transportation Agency	Description of Field Tool
Iowa	Notebook PC accessing PONTIS for inspection
Maryland	PDAs (Personal Digital Assistant) to access PONTIS for bridge inspection
Massachusetts	Integrated Bridge Inspection Information System (IBIIS) is used for electronic data collection, storage, and retrieval using a Notebook PC and video camera (Leung 1996).
Michigan	Bridge inspectors use handheld touch-screen computers. Sketches and photographs can be incorporated into the handheld computer and downloaded at the office along with other field inspection data (Aveni 2001).
Pennsylvania	Experimental use of wearable computers for field inspection data collection (Sunkpho and Garrett 1998, 2002).
South Carolina	Pen-based notebook computers access the Automated Bridge Inspection System (ABIS) to enter inspection data
Ontario Canada	Pen-based input (with numeric touch pad and drop down pick lists) and voice recognition (for comments) used to enter field inspection reports. (personal communication with Don Hamilton, EarthTech-Edmonton)

Benefits

The documented potential benefits of enabling bridge inspectors to electronically record data in the field for later transfer to a centralized database, where the data can be managed and analyzed include the following (Navarrete 1999):

1) Reduced workload and costs
2) Qualified data
3) Shortened analysis time
4) Stored and easily accessible information

The quantifiable benefit of technology for field data collection is in terms of time savings. Time savings leads to increased productivity. Inspectors realize time savings by immediately entering data into the files, instead of copying down information and inputting it later. Errors can be detected immediately, avoiding a further, unnecessary inspection. Michigan DOT realized a cost savings of nearly fifteen percent (Aveni 2001).

Non-quantifiable benefits may be realized through improved data quality, consistency, and completeness. New technology may help with consistently identifying bridge conditions. For routine inspections, new technology may reduce the variability in

element-level inspection ratings, inspection notes, and photographs (Phares and Rolander 2001).

The benefits of IT implementation should be assessed before the decision to invest. The assessment may be an economic analysis such as payback period or a qualitative description of benefits and or other factors (Simmons 1994). Table 1-3 describes the types of benefits that can result from investment in information technology (Simmons 1994).

Table 1-3. Benefits of information technology implementation

Type of Benefit	Description	Measure
Increased Efficiency	Benefits attributed to cost avoidance or reduction	Economic, through cost avoidance or reduction.
Increased Effectiveness	Provide better information for decision making	Economic, through use of information.
Added Value	Benefits which enhance the strategic position of the organization	Usually no direct measure for IT system alone. Evaluate return from entire business strategy.
Marketable Product	Development of marketable product or service	Economic, through establishment of market price.
Development of Corporate IT infrastructure	Communication networks, hardware, database environments that provide little direct benefit but are required as a foundation for other systems	Usually no direct measure. Corporate policy decision

Technology Implementation

Various technology implementation methodologies (Endsley 1994; Turban 1996; Smidts 1995; Vaneman and Trianfis 2001) were considered for guiding the process of selecting, introducing, and implementing the bridge inspection support tool. Helpful implementation methodologies describe the steps to follow for successful implementation including introducing the new technology or process, training end users, formulating a means of feedback, and fully implementing the new technology. The objective is to increase the potential for success (Griffith and Zammuto 1999).

Table 1-4 lists the steps for an implementation process that considers the ongoing relationship between individuals involved in developing a system (Turban 1996). This implementation process relies on the designers and users working together to create a successful decision support system. Users and designers must develop a trust in each other's abilities otherwise the process suffers. The termination or turnover stage is possibly the most important in the entire process. The users must feel they actually own the new system and embrace it. A part of the process includes proper training for smooth operation of the system. If this is done properly, the end users will be comfortable and embrace the change.

Table 1-4. Process for implementing decision support systems

Step	Activity
Initiation	The first contact between the users and the designers
Exploration	Get a feel for the problem at hand
Commitment	Make a decision to proceed with a system

Step	Activity
Design	Develop the logical design and specifications for the system
Testing	Verify that the system works through relevant use
Installation	Convert from the previous system to the new system
Termination	Design team finishes work and transfers ownership to the users
Operations	Routine operation plus enhancement and maintenance

A disadvantage to a new technology is resistance. The technology needs to add value to the process and save time in comparison to traditional methods. The new form of technology introduced to field inspectors must be taken into consideration when implementing a new process (Anthes 2001). If the tools are not designed to take account of the field context and the abilities and preferences of the field personnel, field personnel will not use these tools (Garrett 2002).

Table 1-5 lists the phases for an implementation model designed to reduce the resistance to technological change (Endsley 1994). End-user involvement and flexibility in the proposed change are key success factors. Introduction is the phase when others in the organization learn of the upcoming technology change. The initialization phase is when users get first-hand exposure to the new technology. New work methods and procedures are introduced in this phase. Early job experiences are monitored after the training has been completed. Institutionalization occurs after feedback related to the early job experiences with the technological change.

Table 1-5. Model for reducing resistance to technological change

Phase	Consideration for successful implementation
Initial decision	Including end-users in the decision process is extremely helpful. Successful implementation is highly dependent upon the individuals involved in the decision-making process. The proposed change needs to be seen by employees as an improvement to their welfare or productivity.
Introduction	Past experiences regarding change are important to the employee's perception of new technology and change. The individual's behavior is linked to the consensus of the group. Supervisors and managers play an important role by the attitude they display towards the technological change.
Initialization	Training is the major portion of technology initialization. The most important aspect is that the training received by the personnel be adequate and realistic preparation for the task.
Early job experiences	Experiences may be attributed to change in the social organization of the work environment rather than the technology change itself. It is infinitely important to ensure that the users have developed necessary skills for the technology so they can desire the change. Commitment levels of users stay high when the new system is in-line with their expectations.
Institutionalization	The technological change becomes an accepted part of the system and organization. The degree to which the technology is accepted depends on employee commitment and attitude, supervisor reinforcement and continued training.

Methodology and Project Overview

This research methodology is based on the framework model for reducing resistance to technological change (Table 1-5). The field tool for bridge inspection was identified and developed in four phases:

- Select tool – initial decision
- Training
- Early experience
- Recommendation for institutionalization

Chapter 2 of this report describes that tool selection and technology choices. The tool selected is a Tablet PC. Tool selection involved end-users and was based on the guiding principle that change is motivated by improvement. The technology options considered include PDAs, Tablet PCs, and Wearable PCs. Other considerations for selecting the field tool technology include the desire to minimize software development and subsequent maintenance, and the desire that the tool provide consistent look and feel to the end-user in both the field and the office.

Chapter 3 of this report describes the process and materials that were developed for introducing bridge inspectors to the Tablet PC and for training volunteer inspectors at six Districts. Chapter 4 presents an analysis of the voluntary usage of the field tool including technology adoption and feedback from end-users. Chapter 5 summarizes the findings of this research and presents recommendations for implementation.

Chapter 2 Technology Choice

Requirements and Criteria

The Research Team met with WisDOT Bridge Section Engineers in February 2003 to identify and prioritize a list of desirable functional capabilities for the field inspection tool. The results of those brainstorming sessions are summarized in Table 2-1.

Table 2-1. Prioritization of Functional Capabilities for a Bridge Inspection Field Tool

Priority	Functional Characteristic	Comment
High	Durability	The minimum replacement cycle for WisDOT current notebook computers is two years. The equipment must survive at least two years of field use without failure due to minor impacts, weather, or dust.
	Hand writing recognition	This capability could save time. Time savings depends on the quality of character recognition and the inspector's abilities to use the system. The handwriting recognition needs to be tested to determine how well it will work in the field.
	Electronic Pocket manual on the server side	An electronic bridge inspector's pocket manual would eliminate the need to carry a paper copy. Keeping the electronic manual on the server side would allow the agency to update and distribute the manual quickly.
	Digital camera	The ability to capture, store, and annotate images associated with the inspection. Images could be annotated in the field or later in the office.
Medium	Voice recognition	Possible limitations due to ambient noise need to be minimized. Voice recognition would only be used for data input, not for an audio of a detailed inspection procedure.
	Sketching bridge elements	The ability to draw and store hand sketches associated with the inspection. This capability would be more useful for in-depth inspections.
Low	GPS location referencing	Ability to support location based services. The GPS would be an added cost that probably wouldn't provide any added benefits.
	Wireless network/Dial-up Internet	The wireless capabilities may not be practical at this time because of the remote locations of bridges.
	Bridge Plans	Bridge plans are currently not used by inspectors in the field and probably would not be used if included in the system.

Field Tool Selection and Configuration

Hardware options that were considered include both general-purpose equipment (such as Personal Digital Assistant (PDAs), and Tablet PCs) and commercially available specialty hardware (Wearable PCs).

PDAs are pocket-sized, hand-held computers with very small display screens (about 3 inches). They are intended to replace personal organizers providing handwriting recognition and touch screens. The latest generation of PDAs provides a range of functionality such as built-in digital camera and wireless connectivity. PDAs are the least expensive of all of the hardware options. However, the HSIS inspection screens being developed for WisDOT were not designed for a small PDA screen. Selecting a PDA for the field tool means that a new inspection form would need to be designed, programmed, and maintained. In addition, specialized database software (not currently supported by WisDOT) would be required to enable the PDA to communicate with the HSIS database for data download and upload. Tablet PCs combine the touch screen and handwriting features of the PDA with the computing power of a notebook computer in a compact and light weight design (Microsoft 2002). A wearable computer is a "fully functioned, body-worn computer for hands-free, feet-free operation with speech activation, command, and control" (Steven Mann 1998). Moreover, it is a computer that is always with the user, is comfortable and easy to keep and use, and is as unobtrusive as clothing (Wearable Computing FAQ 1997). Wearable computers are custom configured and programmed for the intended use, consequently they are much more expensive than a Tablet PC or PDA.

The Research Team met with WisDOT Bridge Section Engineers in February 2003 to demonstrate the Tablet PC operations and summarize recommendation for using a Tablet PC rather than PDA for the field tool. The Tablet PC was selected because it is more likely to be accepted by the DOT inspectors, its computing capabilities, and the potential to reduce or eliminate software development and maintenance costs. The Tablet PC was selected for developing the field tool based on its ability to support the functional requirements (Table 2-1) and the following considerations:

- **End-user of the inspection form experiences the same look and feel in the office as in the field.** Convertible Tablet PCs can be used in notebook (with keyboard) or slate (with touch screen) mode. The Tablet PC has a screen size that is comparable to notebook and desktop computers.
- **Easy to use.** The Tablet PC has a familiar operating system and interface functionality is optimal for implementation.
- **Minimize costs for software development and maintenance.** The Tablet PC has hardware and software compatibility with desktop and notebook computers. The inspection forms being developed and maintained for the HSIS can be easily ported to the Tablet PC for field use, thus the agency will not have to develop and maintain a custom inspection form for the field tool.
- **Support for multiple business applications.** The Tablet PC can be used as a notebook computer. It can be connected to the agency's network. The Tablet PC computers can run all other applications that are currently being run on the inspector's desktop machines. Thus, the computing equipment used for the field data collection is also used

in the district office for general purposes. This will maximize the use of the machines and eliminate the need to purchasing special computers for bridge inspection.

Hardware Technology Choices

Two Tablet PCs were considered: Acer and Fujitsu. In the end, the Acer Tablet PC was selected for development and testing of a field data collection tool. The decision was made in conjunction with WisDOT Central Office and based on a comparison of their features summarized in Table 2-2.

Table 2-2. Comparison of Tablet PC hardware choices

Feature	Tablet PC	
	Acer	Fujitsu
Type	Convertible	Slate
Screen Display	Thin Film Transistor (TFT) LCD	Reflective TFT LCD
Pen Stylus Input	Electro Magnetic Resonance (EMR)	Pressure Sensitive
Voice Package	Microsoft Speech Recognition	Must be purchased separately

Type. The convertible-type Acer Tablet PC can function as a portable notebook computer; it comes with an integrated keyboard, external CD Rom, has connectivity ports, etc. Convertible-type Tablet PCs closely resemble laptops, although slightly smaller. An integrated keyboard allows them to be used in the slate mode or laptop mode (Acer 2002). In an attempt to minimize weight, slate-type Tablet PCs do not come with an integrated keyboard. The Fujitsu Tablet PC is designed to be an outdoor data collection device; it is a slate-type Tablet PC (no keyboard) and comes with limited connectivity.

Screen Display. Table 2-3 compares LCD (liquid crystal display) screen technologies in various lighting environments (personal communication with Geoff Walker, Technology Editor, Pen Computing Magazine). The Acer Tablet PC has a "standard transmissive" LCD screens have a strong light in the back of the screen that makes the LCD viewable. But, direct sun light on the screen simply overpowers the back light making the display unreadable. Fujitsu Tablet PCs come with a "reflective" screen. It has a mirror on the back of the screen. The brighter the sun, the brighter the display looks. However, the screen display works poorly indoors. Fujitsu also make a model with a "transreflective" screen that has both a "side light" and a mirror on the back of the LCD.

WisDOT Bridge inspectors at District 1 (personal communication with Matt Murphy) told the Research Team that most of their data entry (90%) occurs while standing under the bridge in shaded sunlight where visibility with a transmissive screen is not a problem. The Research Team investigated possible anti-reflective coatings that can be added to the Acer screen to improve the visibility in bright sunlight without degrading the screen visibility indoors. This strategy would convert the Acer's "standard transmissive" screen to a "treated transmissive" screen. One of the most common screen modifications is to adding anti-reflective (AR) coatings to the surface of the LCD (Walker 2001). With an anti-reflective coating, the screen is very readable in the shade, but in the sun it may only be marginal. Still, for the bridge inspection task, it is acceptable and considerably better than an untreated transmissive LCD (personal communication with Geoff Walker, Technology Editor, Pen Computing Magazine).

Pen Stylus Input. The input digitizers are very different on the Fujitsu and ACER Tablet PCs. The digitizer is a thin layer applied on top of the LCD that makes the pen operations possible. The Fujitsu 3500 uses a Pressure Sensitive (passive digitizer) input mode as compared to the Electro Magnetic Resonance (EMR) (active digitizer) for Acer. Handwriting input on the Fujitsu is through pressure; actually requiring heavier pressure than for normal writing on paper. Thus while the handwriting style is very legible only partial letters are being input. In contrast, the ACER inputs through communication between the pen and screen with very little pressure on the screen. The same handwriting style is much more likely to be interpreted correctly with an active digitizer than passive digitizer. (More recent models of Fujitsu Tablet PC use an Active Digitizer.)

Voice Package. Both of the Tablet PCs support speech recognition. However, the Fujitsu Tablet PC does not include speech recognition software. Using the Fujitsu would require the purchase and installation of third party speech recognition software such as Dragon Naturally Speaking from ScanSoft Inc. for each Tablet PC. On the other hand, the Acer uses Microsoft Windows XP Tablet PC Edition operating system that includes the Microsoft Speech Recognition software installed and ready to use. Mixed reviews are found on discussions in Usenet newsgroups and online forums regarding the performance of Microsoft Speech Recognition engine. Some users prefer the built-in Microsoft Speech engine. These users comment that the built-in speech engine works as well or better than Dragon Naturally Speaking. Using the built-in speech recognition software for the bridge inspector's field tool saves the cost of software license fees.

Table 2-3. Comparison of LCD screen technologies

LCD Technology	In the dark	In normal indoor lighting	Outdoors in the shade or heavy overcast	Outdoors in full sun
High-Brightness Transmissive	Excellent, have to reduce the brightness	Excellent, have to reduce the brightness	Excellent	Adequate to very good, depending on the backlight brightness
Standard Transmissive	Excellent, have to reduce the brightness	Excellent	Barely useable	Completely unusable
Treated Transmissive	Excellent, have to reduce the brightness	Excellent, fully saturated colors	Very good, may have some color shift	Adequate if the anti-reflective coating is good enough; may have some color shift; as the sun gets brighter, the screen gets harder to read
Transflective	Very good, but low contrast mutes colors	Adequate, but low contrast mutes colors	Poor; backlight has no effect at all and there's not enough ambient light for good reflectivity	Adequate; as the sun gets brighter, the screen gets easier to read

LCD Technology	In the dark	In normal indoor lighting	Outdoors in the shade or heavy overcast	Outdoors in full sun
Reflective with Frontlight	Good, but very low contrast	Adequate, but very low contrast	Poor to adequate, with low contrast	Good; as the sun gets brighter, the screen gets even easier to read
Pure Reflective	Completely unusable	Barely useable	Poor to adequate, with low contrast	Good; as the sun gets brighter, the screen gets even easier to read

A ruggedized Tablet PCs is newly available from Panasonic (Toughbook CF-18). Ruggedized Tablet PCs are tested for durability under extreme conditions. Some of the tests that are performed on these units include drop/impacts, altitude, dirt/dust, humidity/moisture, temperature/thermal shock, vibration, and water resistance (ETAC. (2002). These ruggedized Tablet PCs cost about twice as much as a standard Tablet PCs. The Panasonic Toughbook CF-18 ruggedized Tablet PCs costs about $4000.

Field Tool Assembly

The field data collection tool assembly listed in Table 2-4 was purchased for inspectors at 6 Wisconsin DOT districts and tested by district Bridge Inspectors. Each assembly includes Tablet PC with screen protector and sunlight filter, carrying case with shoulder strap, pen tether with swivel, high-quality noise-canceling microphone for speech input, and DC/AC inverter for in-vehicle battery recharging. The technical specs are listed in Table 2-4.

Table 2-4. Technical Specifications for the Field Data Collection Tool

Component	Description
ACER Tablet PC TMC104CTi	10.4 inch XGA TFT with EMR based Digitizer Intel Pentium III 900 MHz – M; 256 MB SDRAM 40GB ATA/100 Hard Drive with Anti Shock protection External IEEE 1394 FireWire DVD/CD-RW Combo Drive 10/100 Ethernet and 802.11b Wireless LAN 56K V.90 Data/Fax Modem; Full Size Pen Microsoft Windows XP Tablet PC Edition http://www.acer.com
Screen Protector and Anti-Reflective Filter	OCLI 110 Gloss HEA 2000 High Efficiency Anti Reflective Film (Part No. F5-F0801-030) The films diffuse the ambient light to make the transmissive LCD more readable. Reported to increase contrast by 40% and reduce glare and reflection by 95% (as compared to untreated LCD) http://www.ocli.com/products/hea_products.html
Tablet PC Carrying Case	http://www.acer.com
The Boom Microphone	Patented noise canceling microphone with interface for cellular phones and PC. Similar systems used for military purposes and on the stock exchange floor http://www.theboom.com
Belkin AC Anywhere	Power up to 300W;Automatic Shutoff

Component	Description
300 W DC/AC inverter.	Low voltage warning; 2 AC outlets http://catalog.belkin.com
Deluxe Pen Tether (with swivel)	Fujitsu FMWST2 http://webshop.fujitsupc.com

Electronic Pocket Manual

To assist inspectors on the field, WisDOT provided a pocket manual that contains detail information about the condition states of every bridge elements and the specific actions relevant to the condition, for each of the condition states. Inspectors carry the manual to the field, and refer to the manual as needed while completing the inspection form. An electronic version of the Pocket Manual can be hyperlinked to the inspection form. With this electronic version, inspectors can click a button in the electronic inspection form to display the relevant information that they need concerning a particular bridge element. Naturally, the inspectors do not have to carry or handle the manual in its physical form to the field, and central office can quickly and immediately update and revise the manual if there are changes. The changes can be used immediately on the field, without the need to wait for physical publishing to take place.

The Pocket Manual was provided to the Research Team as a Microsoft Word document (DOC file). The Research Team then used DOCtoHTML Translator Version 1.3 Freeware to convert the file to HTML. The challenge is to convert the word document into HTML and preserve the formatting in the process. After the DOC file was converted, the sections from the HTML code generated by the converter were pasted into their respective locations in a Microsoft Access database that was set up to generate HTML documents from the entered data. The idea behind this database is to allow easy maintenance and updating of the pocket manual contents. The last step was setting up a one-to-one correspondence between the Element Numbers and the respective subsections in the pocket manual for easy one-click viewing (i.e. setup a table with subsection page corresponding to each Element number). A button can easily be placed in the inspection form that will link to the information for the appropriate element. This context sensitive access to the electronic pocket manual will make it easier for inspectors to reference the pocket manual at the bridge site.

Chapter 3 Testing and Implementation

Getting Participation and Buy-in from Inspectors

Bridge inspectors have an important role in selecting the computing devices that best support the field inspection process. The Research Team identified several possible concerns from the point of view of the inspectors:

- Is the tool acceptable to the inspectors?
- Does the tool provide a familiar user interface (same in office as in the field)?
- Does the equipment provide a seamless transition from the Notebook PC that is currently used by inspectors?
- Can the tool be used as an office PC?

Members of the Research Team (Mohsin Siddiqui and Jim Dzienkowski) attended the Spring 2003 Inspector Training Session (Wisconsin Rapids on May 28, 2003). At that meeting the Research Team provided an introduction to the Tablet PC technology to 20 bridge inspectors from Wisconsin's eight districts. The purposes of the presentation include the following:

1. Update/inform the bridge inspectors on the project objectives, progress and plans.
2. Provide a brief demonstration of the Tablet PC functionality and use as a tool for field data collection. Demonstrated speech and handwriting recognition capabilities.
3. Gain interest and commitment among inspectors to participate in the testing phase of Field Tools Project.
4. Personally meet and begin establishing working relationship with participating bridge inspectors.

Training Bridge Inspectors to use the Tablet PC

At the Spring Inspector Training Session in Wisconsin Rapids, 6 districts (1, 3, 4, 5, 6, and 8) were identified for participating in the testing phase of this project. The Research Team developed a training plan and agenda, and then met with Matt Murphy in District 1 for a pre-training demonstration of the field tool and to refine the training plan.

The Research Team scheduled training sessions at each participating district. Table 3-1 lists the bridge inspectors and bridge engineers who participated in the Tablet PC training. The Research Team traveled to each participating district to deliver, set up the Tablet PC technology, and conduct the training. At each district, training on the Tablet PC included accompanying the inspector in taking the technology out to the field to inspect a bridge.

The agenda for the day-long training session is shown in Figure 3-1. The training materials (see Appendix A) were developed to guide the training process. A user reference guide, "User Guide for Tablet PC as a Field Tool" (see Appendix B) was written to provide quick relevant information for the inspectors as they become familiar with the Tablet PC technology. To collect data for evaluating the Tablet PC as a field tool, the participating inspectors were asked to complete a questionnaire (see Appendix C) each week that they used the Tablet PC for inspecting bridges.

Table 3-1. Participating Bridge Inspectors and Engineers and Tablet PC Training Schedule

Bridge Inspector/Engineer	District	Location	Date
Jim Oettinger, Matt Murphy	1	Madison	June 24
Jim McDowell, Dale Weber	3	Green Bay	July 8
Tom Hardinger	4	Wisconsin Rapids	July 1
Greg Haig	5	La Crosse	July 9
Steve Severson, Patrick Kern	6	Eau Claire	July 15
Allan Bjorklund, Dan Harrington	8	Superior	July 2
Dave Babler, Shiv Gupta, Stan Woods, Travis McDaniel	Central Office	Madison	August 21

Tablet PC Training Agenda

- Conduct Preliminary Questionnaire
- Tablet PC Introduction
- User Guide for Tablet PC as a Field Tool
- Input Interfaces
  - Handwriting
  - Voice
  - Onscreen/External Keyboard
- Electronic Inspection Form Operation
- Experience at a bridge site
- Instructions for completing and submitting Weekly Questionnaires

Figure 3-1. Agenda for Tablet PC Training at Participating WisDOT Districts

Chapter 4 Evaluation

Information and data for evaluating the Tablet PC field tool was collected via a questionnaire that the participating inspectors submitted each week they used the Tablet PC for bridge inspection. The first part of this chapter summarizes the results of the weekly questionnaires that were submitted back to the Research Team. During the testing phase, inspectors reported trouble in using the voice recognition feature. The second part of this chapter presents the result and recommendations from experiments using the speech recognition technology.

Weekly Questionnaire

The purpose of the weekly questionnaire is to gather information to allow the Research Team to compare the field inspection experience with and without the Tablet PC and to survey inspectors on their use and productivity with the field tool on a weekly basis. The questionnaire (see Appendix C) gathered data for measuring the inspector's ability to develop skills in using the handwriting and speech recognition technologies and the associated productivity impact. Questions on the weekly questionnaire allowed inspectors to rate several aspects of the Tablet PC.

In the period of July to October 2003, 18 weekly questionnaire responses were received from five participating inspectors (Districts 1, 3, 5, 6, and 8). Data from the questionnaire responses forms the basis for the analysis presented in this section.

Of the 18 questionnaire responses received, 13 indicated some use of the Tablet PC during the week (see Table 4-1). The inspectors who used the Tablet PC, tended to use it for most or all data entry. The inspectors carried their Tablet PCs to the bridge site, however most responses indicated that the inspectors prefer to enter most or all data while sitting in their vehicle. Almost sixty percent of the responses indicated that the paper form was not used in the inspection process. Seven of the 18 responses indicated that the inspector used the paper form in addition to or instead of the electronic form on the Tablet PC. Inspectors gave the following reasons for using the paper forms (note that one response indicated two reasons for using the paper form):

- Poor Voice Recognition (2 responses)
- Small bridge inspection, box culverts (2 responses)
- Takes too long to load and send to Madison (1 response)
- Glare (2 responses)
- Weather (1 response)
- No reason (1 response)

Table 4-1. Did inspectors use the Tablet PC?

Technology choice	Percent of weekly responses (Total responses = 18)			
	All data	Most data	Some data	Not used
Tablet PC was used to enter	29.4	29.4	17.7	23.5
In Vehicle use of Tablet PC to enter*	30.8	61.5	0	7.7
Paper Forms used to collect data	11.8	23.5	5.9	58.8

* Tablet PC users only (13 responses)

Some inspectors reported the location where they transcribed information from the paper form into the database. One inspector transcribed half of the information in the office on the Tablet PC, and the other half in the office on a Desktop PC)

- In vehicle on Tablet PC (1 response)
- In office on Tablet PC (4 responses)
- In office on Desktop PC (3 responses)

Table 4-2 shows the usage of Tablet PC at the bridge site. All inspectors who tried were able to enter and edit notes in the text boxes at the bridge site. Inspectors clearly preferred to use the handwriting recognition over the speech recognition technology or the on-screen keyboard.

Table 4-3 shows the usage of Tablet PC in inspector's vehicles. When in their vehicles, inspectors tended to use the Tablet PC as a notebook. They were twice as likely to use handwriting recognition to enter notes as the speech recognition. When entering notes, many inspectors use the on-screen keyboard.

Table 4-2. How did inspectors enter data at the bridge site?

Tablet PC usage	Percent of weekly responses (Total responses = 13)	
	Yes	No
Enter/edit notes in the text boxes	100	0
Use speech to enter notes	46.2	53.8
Use handwriting to enter notes	92.3	0.7
Use on-screen keyboard	53.8	46.2

Table 4-3. How did inspectors enter data in their vehicles?

Tablet PC usage	Percent of weekly responses (Total responses = 13)	
	Yes	No
Used Tablet PC as a notebook computer	55.6	44.4
Used speech recognition to enter notes	33.3	66.7
Used handwriting recognition to enter notes	66.7	33.3
Used on-screen keyboard	77.8	22.2

The inspectors rated the Tablet PC characteristics and their experience using it. Table 4-4 summarizes the rating criteria and responses sorted from highest to lowest rating. Inspectors generally liked the Tablet PC, its pen stylus, and carrying case. Inspectors indicated some confidence in the equipment's ability to survive for 2 years of normal field use. Inspectors were willing to use the computer as an office machine, although some inspectors prefer a larger keyboard, monitor, and full size mouse.

Table 4-4. How did the Inspectors rate the Tablet PC?

Rating Criteria	Average Score (5=high, 1=low)
I like the size and weight of the Tablet PC.	4.6
I like the pen stylus (handwriting) input.	4.2
I find the Tablet PC easy to operate.	4.1
I would use this Tablet PC for other office or field jobs.	4.1

Rating Criteria	Average Score (5=high, 1=low)
I can easily handle the Tablet PC with the shoulder strap and carrying case.	3.9
The Tablet PC screen size is large enough to view the inspection forms.	3.8
The Tablet PC is durable (able to survive 2 years of field use).	3.6
I have used this Tablet PC for other office or field jobs.	3.6
The Table PC's battery life is adequate.	2.8
I find the headset for speech recognition comfortable	2.7
I like the speech recognition data input.	2.4
I can clearly read the screen in outdoor lighting.	1.9

The weekly questionnaire provided a comments/suggestions area for the inspectors to give feedback and to describe their experience in using the Tablet PC for bridge inspections. The following comments were transcribed directly from the questionnaires. Comments 7 and 8 are related to WisDOT's check-in/check-out process that the Districts must go through to access inspection records in the HSIS database.

1. "I had to change my handwriting style to be recognized"
2. "I feel my inspection is more accurate when I'm able to complete the form in it's entirety at the bridge"
3. "The microphone picked up traffic noise when out in the field"
4. "Tablet PC usage for box culvert type structures is time consuming"
5. "I need a car charger"
6. "Cannot see clearly under the sun"
7. "Inspection will be easier once the loading data in and out of the machine becomes better"
8. "Check-in/check-out process is complicated and slow"

Adoption of Handwriting Recognition Technology

From the weekly questionnaire responses, the Research Team was able to gather data regarding the inspectors' ability to develop competency in using the handwriting recognition technology. Two inspectors provided data for two or more handwriting usages. The results were used to plot the self-rated learning curves in Figure 4-1. The learning curves show incremental and cumulative percent improvement on using the pen stylus and handwriting recognition. Week 0 indicates the baseline competency at the time of training on the Tablet PC. The curves show that the increase in improvement is very significant in the beginning. The curve flattens when the inspector gets more comfortable with the handwriting recognition technology, and feels that the increased improvement they experience is minor.

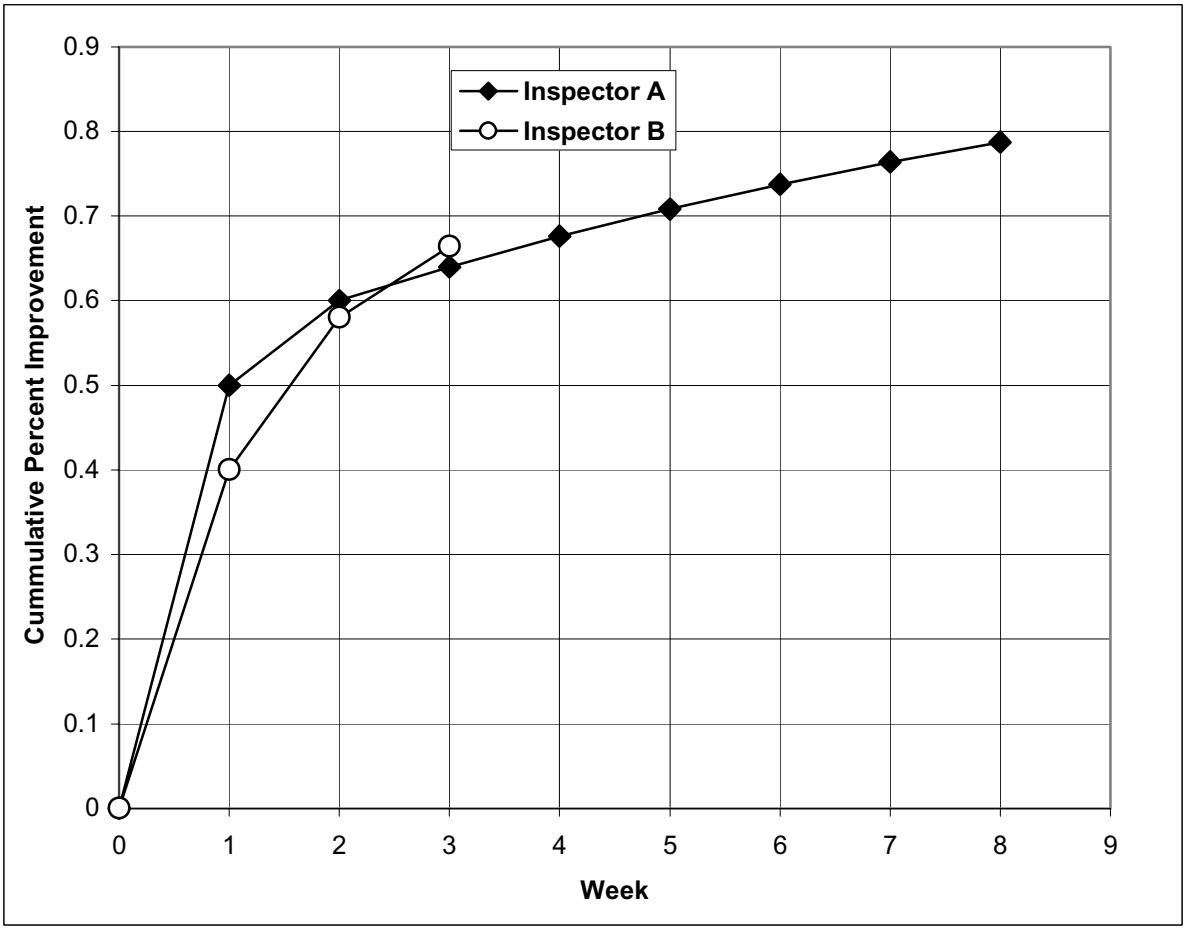

Figure 4-1. Self-rated Learning Curve for Using Handwriting Recognition

Adoption of Speech Recognition Technology

Inspectors were less successful in adopting the speech recognition technology compared to the handwriting recognition technology. At the end of the evaluation period, none of the participating inspectors used the speech recognition technology on the Tablet PC. These results totally contradict what was expected. In selecting the field tool technology, the Research Team consulted with EarthTech engineers about their experience using a Tablet PC for bridge inspection in Canada. The EarthTech engineers suggested that inspectors prefer the speech recognition over the handwriting recognition technology and that a high quality noise-canceling headset microphone is a critical success factor for technology adoption. An explanation may be that the Canadians were nearly forced to adopt speech recognition technology. The EarthTech equipment included a Fujitsu Tablet PC with no keyboard and pressure sensitive pen screen input. The handwriting recognition performs poorly on the pressure sensitive screen. The WisDOT inspectors were given a field tool having both a keyboard and easy pen input through Electromagnetic Resonance technology.

Despite the use of high quality noise-canceling microphones, a common complaint about the voice recognition is that it does not work at a noisy bridge site. The Research Team investigated several potential sources of the inspectors' problems with the speech recognition technology:

Hardware. The Research Team tested both the regular PC noise-canceling microphone for hardware flaw in the connector plugs and microphone adapter of "TheBoom" microphone. There were no specific hardware flaws. Tests were also conducted by comparing the accuracy of voice recognition between the two microphones. No problems are found with both of the microphones, and "TheBoom" microphone definitely performed better than the regular noise-canceling microphone.

Software. The Acer Tablet PC uses the speech recognition engine that is bundled with the operating system (Microsoft Windows XP Tablet PC Edition) instead of third party software. Comments from users and experts in voice recognition found in Usenet newsgroups and online forums confirmed that this is not a problem. Although there are users who like third party software, many other users say that the built-in speech recognition engine from Microsoft is just as good as any third party software available.

User (Speech Profile). Two sources were considered. First, the speech profiles used by the inspectors were trained in an office environment, not the ambient highway noise environment as the intended usage. Second, there is concern that inspectors may tend to change the volume and tone of their voice when working in a noisy highway environment. Thus they may be using different voices for training and use.

Based on results from the Research Team's investigation of possible hardware and software problems, the most likely source of the problem is the user and/or inadequate training of the speech profile. The Research Team conducted speech recognition experiments to better understand the adoption of speech recognition technology.

The speech recognition experiments compared five speech profiles that were trained in various noise environments. All profiles were trained by the same person. Table 4-5 lists the specifications of each profile. The "highway" noise environment is located under a bridge and is similar to the actual noise environment during bridge inspection. After each new lesson was added, the profile was tested according to its ability to correctly recognize a 265-word paragraph. Testing was conducted in a highway noise environment. The accuracy rates for each point of each profile are shown on Table 4-5. Accuracy rate is the percentage of the 265-word paragraph correctly transcribed by the speech recognition engine.

Figure 4-2 shows the accuracy rate trend for each profile as a function of the number of lessons used to train the profile. Improved accuracy does depend on the ambient noise during training. However, the accuracy of the profile always improves with additional training, regardless of the training location. The impact of training in a highway noise environment is not conclusive.

From Figure 4-2, it is clear that the accuracy of the profiles increases after each new lesson is added. However, something else is going on too. Consider data points C1 and A4. Although C1 has seven training lessons compared to A4 that has six, the accuracy of A4 is 98.1 while the accuracy of C1 is only 92.5. In general, profiles A and B have higher accuracy rate than the other profiles, although they are based on fewer training lessons.

Table 4-5. Speech profiles trained and corresponding accuracy rate

Profile	Data Point	Number of training lessons in noise environment			Lessons in the profile	Accuracy Rate (%)
		Office	Highway	Construction Site		
A	A1	3	0	0	3	96.2
	A2	3	1	0	4	97.3
	A3	3	2	0	5	98.1
	A4	3	3	0	6	98.1
B	B1	0	3	0	3	96.2
	B2	0	4	0	4	97.7
	B3	0	5	0	5	98.5
	B4	0	6	0	6	98.7
C	C1	4	3	0	7	92.5
	C2	4	4	0	8	97.0
	C3	4	5	0	9	97.4
	C4	4	6	0	10	98.5
D	D1	8	0	0	8	92.8
	D2	9	0	0	9	96.9
	D3	9	1	0	10	97.7
E	E1	0	6	3	9	94.7
	E2	1	6	3	10	95.1

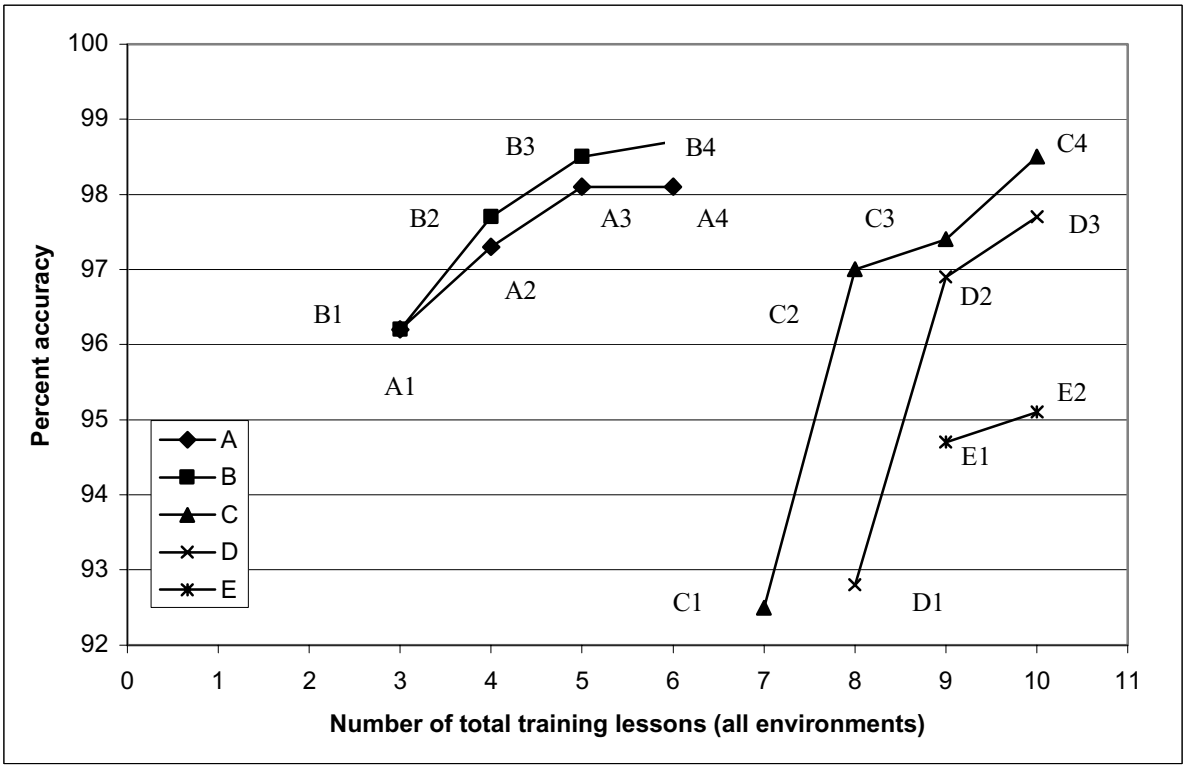

Figure 4-2. Accuracy improvement due to profile improvement

To illustrate the conclusions of the speech recognition experiments, Figure 4.3 shows the accuracy rate trend for each profile as a function of the cumulative training and reading experience of the user. From Figure 4-3 it is clear that the accuracy rate of a speech profile is highly dependent on the experience of the person who trains and uses the profile. Every time a person uses the technology, that person is learning how to speak so that he/she will be better recognized.

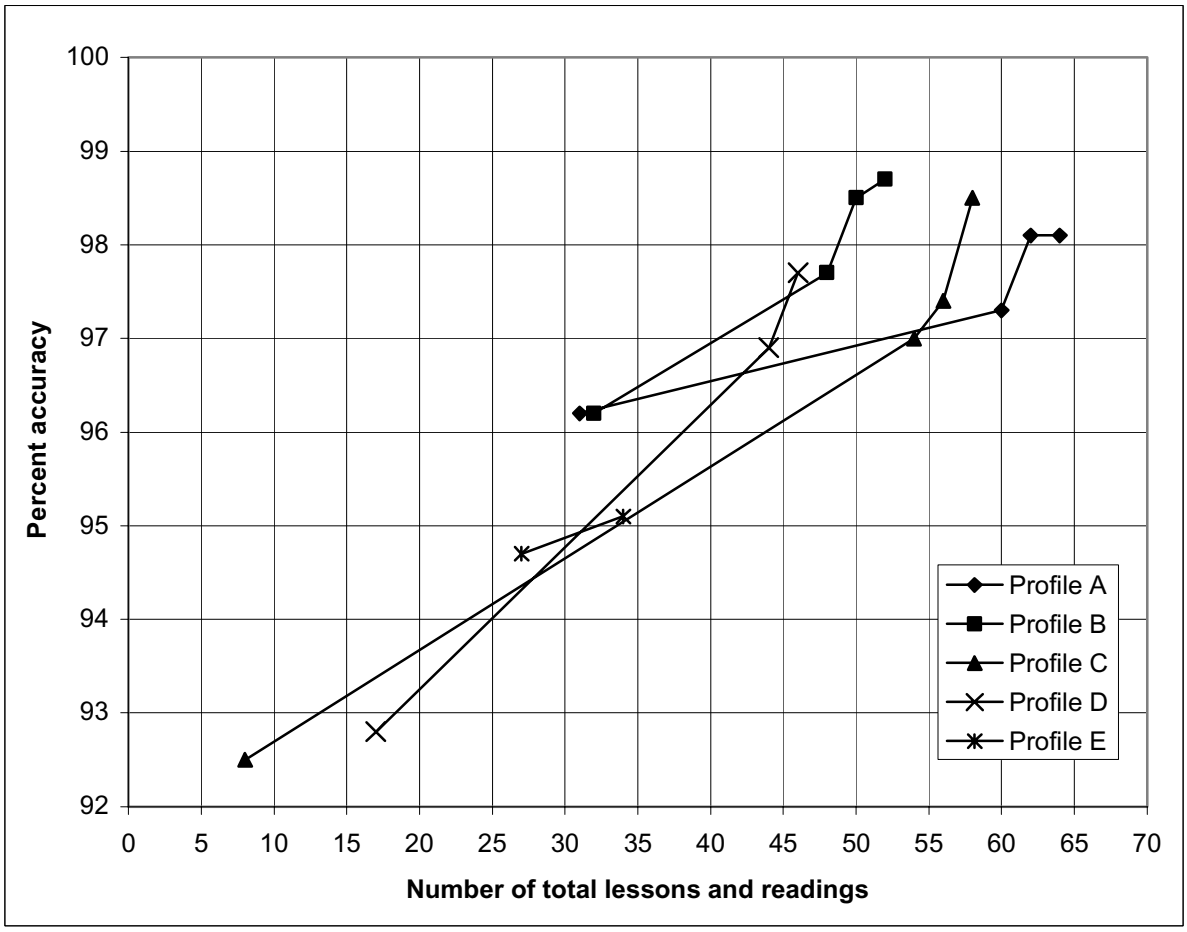

Figure 4-3. Accuracy improvement due to user experience

From Figures 4-2 and 4-3, it can be concluded that speech recognition improves as:

- The profile learns to recognize the inspector's voice through more profile training and profile training in a noise environment that reflects the environment for intended use.
- The inspector learns to talk to the speech engine through more use and familiarity with the technology.

The best ways to improve the speech recognition performance are to:

- Do more training in a highway noise environment; this will increase the profile's accuracy.
- Continue to use the technology; this will increase inspector's experience.
- Speak naturally, clearly, and enunciate; this will help the speech recognition engine correctly interpret what was said.

Payback Analysis

From the weekly questionnaire responses that were received, the inspectors reported a range of 15 to 25 minutes time savings per bridge inspected with the Tablet PC. The Research Team calculated the expected payback period for the Tablet PCs for bridge inspections. The payback period is based on the following assumptions:

- Tablet PC cost: $2000
- Inspector's wage rate: $40/hour (includes fringes)
- Average number of bridges inspected per year: 150

Table 4.6 shows the payback period of Tablet PC usage in number of bridges inspected and years of use. The payback analysis does not include considerations for use of the Tablet PC for computing tasks other than bridge inspections. The investment in implementing the Tablet PC will be returned when 120 to 200 bridges are inspected, or after 0.8 to 1.3 years of use.

Table 4-6. Payback period for Tablet PC usage

	Payback period	
Time savings per bridge inspected (minutes)	Bridges inspected	Years
15	200	1.33
25	120	0.8

Chapter 5 Findings and Recommendations

The overall research finding is that the Tablet PC is a viable and adoptable tool for field data collection. The benefits of deploying the Tablet PC will outweigh costs. The success of this demonstration project was limited due to institutional barriers that made it difficult for inspectors to use the technology in their bridge inspection work process. Inspectors, who made an effort, were able to easily adopt the technology and are enthusiastic about streamlining and improving their work process. Removing the institutional barriers will enable less enthusiastic inspector to easily adopt the technology.

Obstacles to Technology Adoption

Bridge inspectors encountered several frustrations and obstacles that influence their willingness and ability to use the Tablet PC technology for field data collection.

The Tablet PC was introduced concurrently with the HSIS Electronic Inspection Form and new database procedures for reporting field inspection data to Central Office. Software bugs and business process changes associated with the deploying the HSIS Electronic Inspection Form were reflected in the inspectors' reluctance to use the Tablet PC Field Tool. Inspectors were frustrated with the limitations of the new Check-in/Check-out process for retrieving and reporting inspection records. This frustration was evident in their reluctance to participate in the Tablet PC evaluation project.

The Tablet PC is not on the WisDOT "Approved Equipment List," consequently, the Inspectors were not able to connect the Tablet PC to the computing network infrastructure or get technical support such as for virus protection licenses. (Similarly, the Tablet PC uses the XP operating systems. WisDOT is now migrating to XP.) To use the Tablet PC, inspectors had to work through their desktop machines that are connected to the network. Inspectors had to save inspection records onto a CD, copy to the Tablet and then reverse the process to send records back to the Central Office.

Technology Choice

In reviewing the technology choices for the field tool configuration, only a few changes are recommended. It is also important to emphasize the particularly positive features of the tool; that is, what not to change.

"Convertible" Tablet PC is a good choice. The Tablet PC with a shoulder strap and carrying case gives inspectors a paper-and-clipboard ability enter data while standing at the bridge site using handwriting and speech recognition tools. Individual inspectors will likely develop a preference for handwriting or speech recognition; both require some effort to adopt. The use of convertible-type Tablet PC is preferred over a slate-type, because it can also function as a notebook PC in the office or field. Furthermore, when possible, some inspectors do prefer to use the mechanical keyboard attached to a convertible Tablet PC.

Electro Magnetic Resonance (EMR) (active digitizer) is a good choice. The alternative, Pressure Sensitive (passive digitizer) input for handwriting recognition requires much heavier pressure than for normal writing on paper. Inspectors will be much more successful in adopting handwriting recognition technology with EMR digitizer. The market industry is moving to EMR.

Alternative LCD technology choices should be evaluated at the time of purchase. It is important to feature screen technology that is specifically designed for outdoor viewing, but also readable in the office so it can be used as a regular notebook. Given current technology choice for LCD screens (summarized in Table 2-3), "Treated Transmissive" screens offer the best compromise for indoor and outdoor viewing. The Research Team applied Anti-reflective (AR) films to the outside of the LCD screens as a treatment, with minor effects. Factory treated LCD panels may work better. Another option is to connect the Tablet PCs to desktop monitors for indoor use.

Car Adapter is preferred over DC/AC Inverter. Inspectors prefer to have a car adapter for the Tablet PC rather than a multi purpose DC/AC inverter. To use the DC/AC inverter that was provided, inspectors must have the Tablet PC power cords. With a car adapter, the inspectors do not need to bring the power cords. The shoulder carrying case for the Tablet PC does not have place to store/carry the power cords.

Handwriting recognition technology is preferred over speech recognition technology. Inspectors adopted the handwriting recognition technology but not the speech recognition technology. The speech recognition technology was found to be unacceptable for several reasons. First, implementation of speech recognition technology requires up-front and continued effort to develop a robust speech profile. Second, inspectors must speak at a constant rate and concentrate on enunciating clearly so that words are correctly recognized. Third, like learning to dictate a letter, inspectors must compose and dictate complete sentences on the fly. Finally, despite the use of high quality, noise-canceling microphones, background noise from highway traffic interfered with results causing inspectors to frequently edit results.

Train Inspectors to Use the Tablet PC Technology

The Tablet PC training that was provided to the inspectors was well received. Full deployment of the Tablet PC for field inspection must include a training phase. **Inspectors need training on how to use and customize the handwriting and speech recognition tools.**

Benefits

The primary quantifiable benefit of using the field tool for data collection is derived from time savings that results from not having to transcribe inspection data from paper inspection forms. Payback analysis shows considering time savings alone, each Tablet PC would pay for itself in 0.8 to 1.33 years or after 120 to 200 bridges are inspected.

Other benefits include more detailed and accurate inspection data, especially if inspectors adopt the speech recognition technology. Having the Inspector's Pocket Manual hyperlinked to the Electronic Inspection Form, makes referencing the Pocket Manual very convenient. This may lead to more use of the pocket manual and more consistent inspection reports.

The Tablet PC can be used in the field or office. Adopting a Tablet PC as the field inspection tool has an added benefit due to cost savings from avoided cost of purchasing office computers.

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Appendix A: Tablet PC Training Plan

Training Session Objectives

The Research Team is planning on introducing and training the participants adequately to perform bridge inspections with the Tablet PC on their own. The participants will familiarize themselves with the operation of the Tablet PC during the training session. After the participants are comfortable using the machine, the Research Team will accompany the inspector for a bridge inspection.

The office training session is expected to take approximately 2-3 hours. Adequate time should also be scheduled for a bridge inspection, including the needed travel time.

Tablet PC Introduction (20 minutes)

The Research Team will spend a few minutes demonstrating the basic Tablet PC configurations and general startup procedures.

- Tablet PC configurations
- Startup/Shutdown procedure
- Screen configurations
- Function buttons
- Carrying Case
- Microphone headset

This will be done to familiarize users with the new PC and assure successful turnover results at the conclusion of the training period.

Input Interfaces

The different data entry interfaces will be introduced and demonstrated so the users can familiarize themselves with the different options available. The available interface options include the external keyboard, onscreen keyboard, handwriting recognition, and voice recognition.

Handwriting (15 minutes)

This input is very natural for users and will work well for those that possess at least average handwriting clarity. The handwriting inputs are very user friendly. Fifteen minutes should provide enough time to demonstrate the following options and adjustments:

- Text Preview
- Spelling Corrections
- Write Anywhere
- Send Text

Voice Recognition (1 hour)

Some users may not find that the handwriting recognition works well with their particular writing style. Users also may want to find a faster means of entering comments into the inspection forms. Voice recognition offers users the option to speak the information they want recorded and enter it directly into the relevant fields as text.

The voice recognition requires the users to complete training exercises to improve the recognition of words and phrases. One hour will be used to refine the voice recognition of the Tablet PC and familiarize the user with the speech recognition tools such as:

- Additional Voice Training Exercises
- Word Pronunciation Additions
- Text Preview
- Send Text
- Microphone Adjustment

The Research Team will only go through 1-2 voice training exercises with the users because they take additional time and are very easy to complete individually.

Onscreen Keyboard (10 minutes)

The onscreen keyboard is a very easy to use input method, but is probably slower than the other input methods available. General operation and access of the onscreen keyboard will be displayed.

External Keyboard (5 minutes)

The external keyboard can be used when the Acer Tablet PC is configured in the Notebook PC mode. This offers the familiar keyboard data entry in the traditional notebook form.

Formal Bridge Inspection

After users are comfortably prepared to use the Tablet PC to enter data using the voice recognition and handwriting recognition interfaces, the Research Team will accompany the inspector for a routine bridge inspection. Therefore the Research Team would like the inspector participating in the Tablet PC training to select a bridge prior to the training period for a formal inspection.

The Research Team will accompany the inspector on a formal inspection to provide any assistance needed. This will also let the inspector experience everything that might be encountered on a given inspection. The Research Team will be available to help with any operation or configuration problems.

Weekly Questionnaire

After the Research Team turns the Tablet PC over to the inspection team, a means of tracking the benefits and experiences recognized through the use of the machine is required. The Research Team will request that users fill out a weekly questionnaire related to the use of the Tablet PC for bridge inspection. This will help the team recognize productivity gains and locate possible improvements to the system.

Conclusion

After the Tablet PC training and the formal bridge inspection the Research Team feels the users will be adequately prepared to use the field tool for inspection duties. A user guide will be provided in the event the user has trouble with operation. The Research Team will also be available for consultation.

It is expected that users will become more comfortable and proficient with the Tablet PC over time. The additional voice training exercises will help with speech recognition and positively influence user's experiences with the field tool.

Thank you for your participation in the WHRP Field Tools Project. We sincerely appreciate your time commitment and patience.

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Appendix B: Tablet PC User Guide

Integrated Field and Office Tools for Bridge Management Project

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Tablet PC User Guide

Table of Contents

Tablet PC Introduction

The Tablet PC combines the advantages of the Notebook PC and the PDA into one easy to use technology. New interactions with your computer will be available, but some new challenges may present themselves. This could be the result of the spoken and written data entry that is available with the Tablet PC.

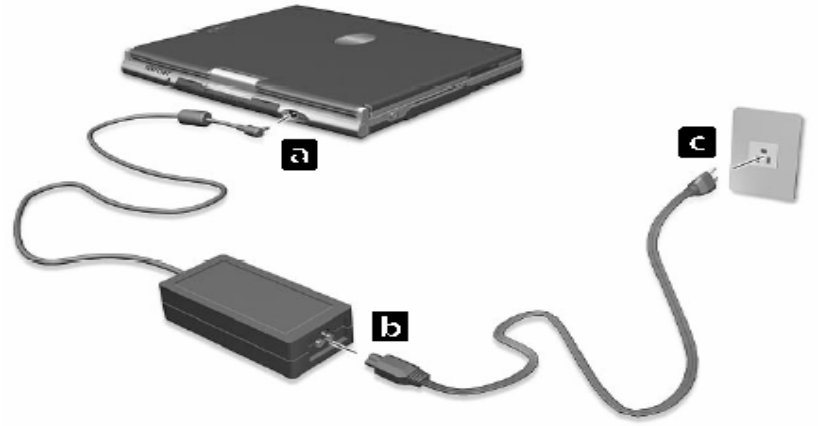
Having the Tablet PC in-hand will make the procedures in this guide easier to follow. More detailed instructions can always be referenced from the Acer User Guide, Acer Application Manual, Acer Pocket Manual, or at www.acersupport.com.

Connecting Your Computer

Connecting your computer can be done very quickly by following a few easy steps. Complete instructions can be found in the Acer User's Guide.

1. Insert the battery pack into the battery compartment, and press down until it clicks into place.

2. Connect one end of the AC adapter to the power jack on the computer's rear panel and the other end to a properly-grounded power outlet.



3. Push the display cover latch to open the display.

4. Slide the power switch towards the rear of the computer (a) then release it (b) to turn on the power. The POST (power-on self-test) routine executes and Windows begins loading.

To turn the power off, do any of the following:
• Click on **Start**, **Turn off Computer**; then click **Turn Off**.
• Use the power switch

Tablet PC Basics

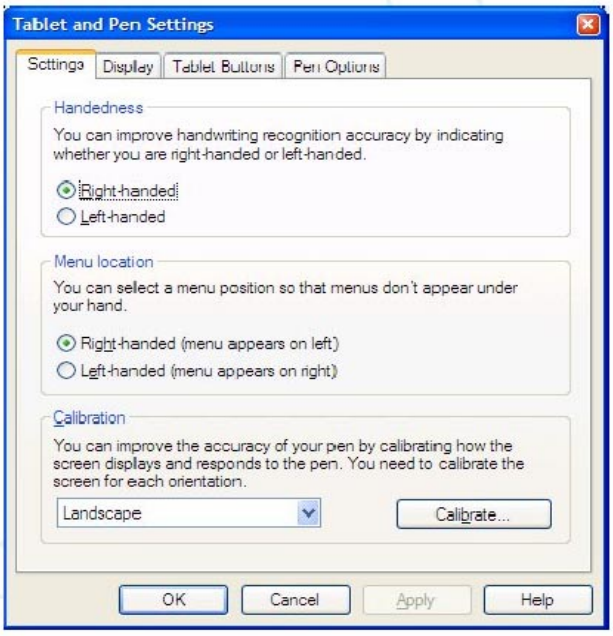
Several basic configurations of the Tablet PC are included in the Acer User Guide along with the location of all port or jacks included on the machine. This can be viewed in detail in the **Acer User Guide on pages 1-15** to familiarize yourself with the Tablet PC.

Changing Tablet and Pen Settings

Either double click the "Change tablet and pen settings" icon in the icon tray, or go to *Start>Control Panel>Tablet and Pen Settings* to open the Tablet and Pen Settings window.

This information can also be found on **pages 9-14 of the Acer Tablet PC Application Manual provided with the machine. The Pocket Manual also explains calibration steps on pages 22-24 in a condensed version.**

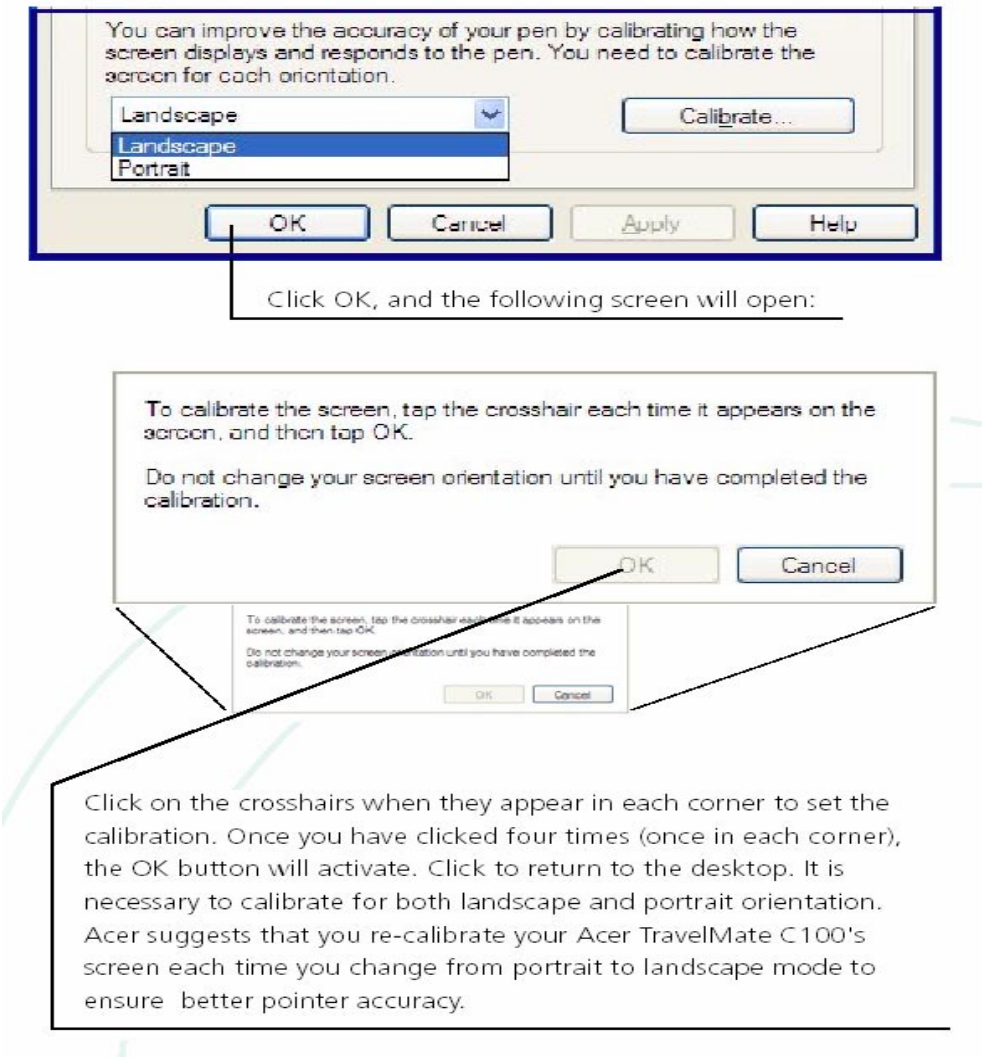
The Settings Tab



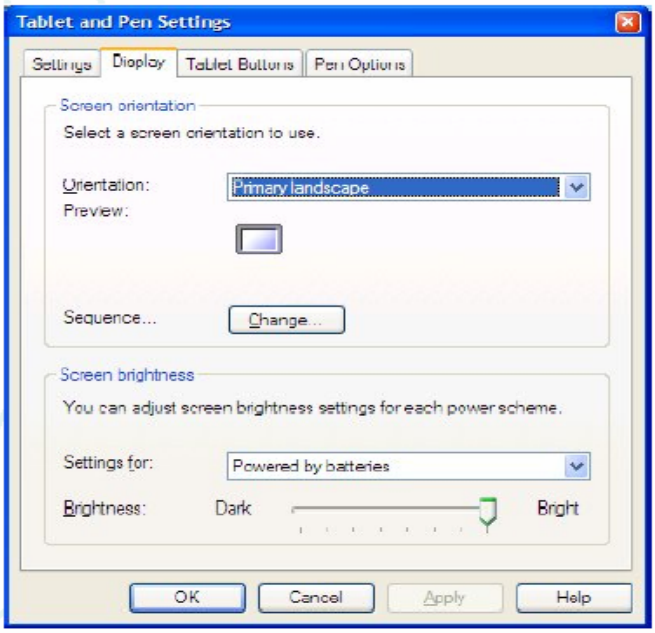
The Tablet and Screen Settings window has four tabs to allow different settings. The Settings tab allows the user to set the screen for optimal use for right- or left-handed use. It also has the option to calibrate the screen for landscape or portrait layout.

Calibrating the screen

Select the orientation you wish to calibrate using the drop down menu, and click the Calibrate button.



The Display Tab



The Screen Brightness can be adjusted under the “Display Tab” which is included in the “Tablet and Pen Settings” window.

The Screen Orientation can also be changed in the Display Tab. Full instructions regarding the Display Tab can be found in the Acer Application Manual.

Tablet PC Input Panel

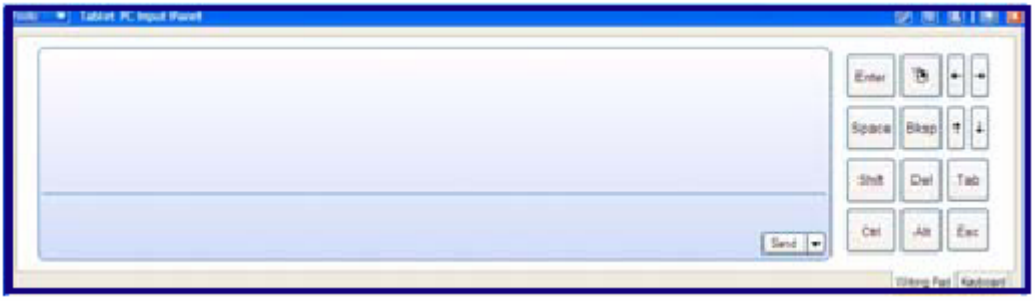
The Input Panel is a convenient area for writing down your ideas in natural handwriting, and converting the handwriting to text input to any compatible application. This material can be reviewed in the **Application Manual pages 15-23** or in the Acer Pocket Manual.

Activating the Input Panel is as simple as clicking on the Input Panel button on the task bar adjacent to the Start button, and the Input Panel will open automatically, or you can use the "Start Input Panel" gesture.

The Input Panel is always on top, so you never need to worry about searching for it, or having it disappear under other application windows.

Choose how you want to enter your data by selecting either the "Input Panel" or "Key board" tabs at the bottom of the window.

The "Input Panel" will open up a blank area for you to write in, and a small keypad on the right with many of the commonly used keys, including Enter, Backspace, Ctrl, Alt and many others. You may use these keys to make changes or to edit formatted text in the application. You may use the "Bksp" button to delete all the text written, or use a scratch-out action to delete text before it goes to the application.



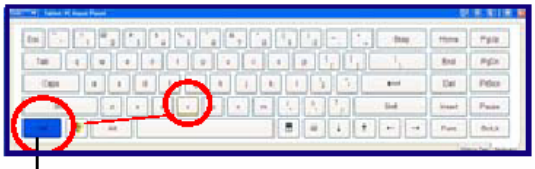
The "Key board" tab will open up the "Virtual Keyboard", which is a standard QWERTY keyboard (similar to those seen on other PCs), right on your input screen.

Using the Input Panel

Simply use the Input Panel as you would with any paper note-pad, jot down your thoughts and notes using the EMR stylus or pen. The Microsoft® Inking technology employed by the Input Panel will show the written text exactly as you wrote it, following the strokes of your pen.

Select the "keyboard" tab to activate the virtual keyboard, which allows you to type using the EMR stylus or pen by tapping on the key you wish to use. Don't worry about how you will use function keys such as "Ctrl" and "Alt", tap gently on the screen above the function key, and it will be highlighted and remain highlighted until you tap the following key in the sequence. For example, if you wish to paste from the clipboard, tap "Ctrl" and then tap "V".

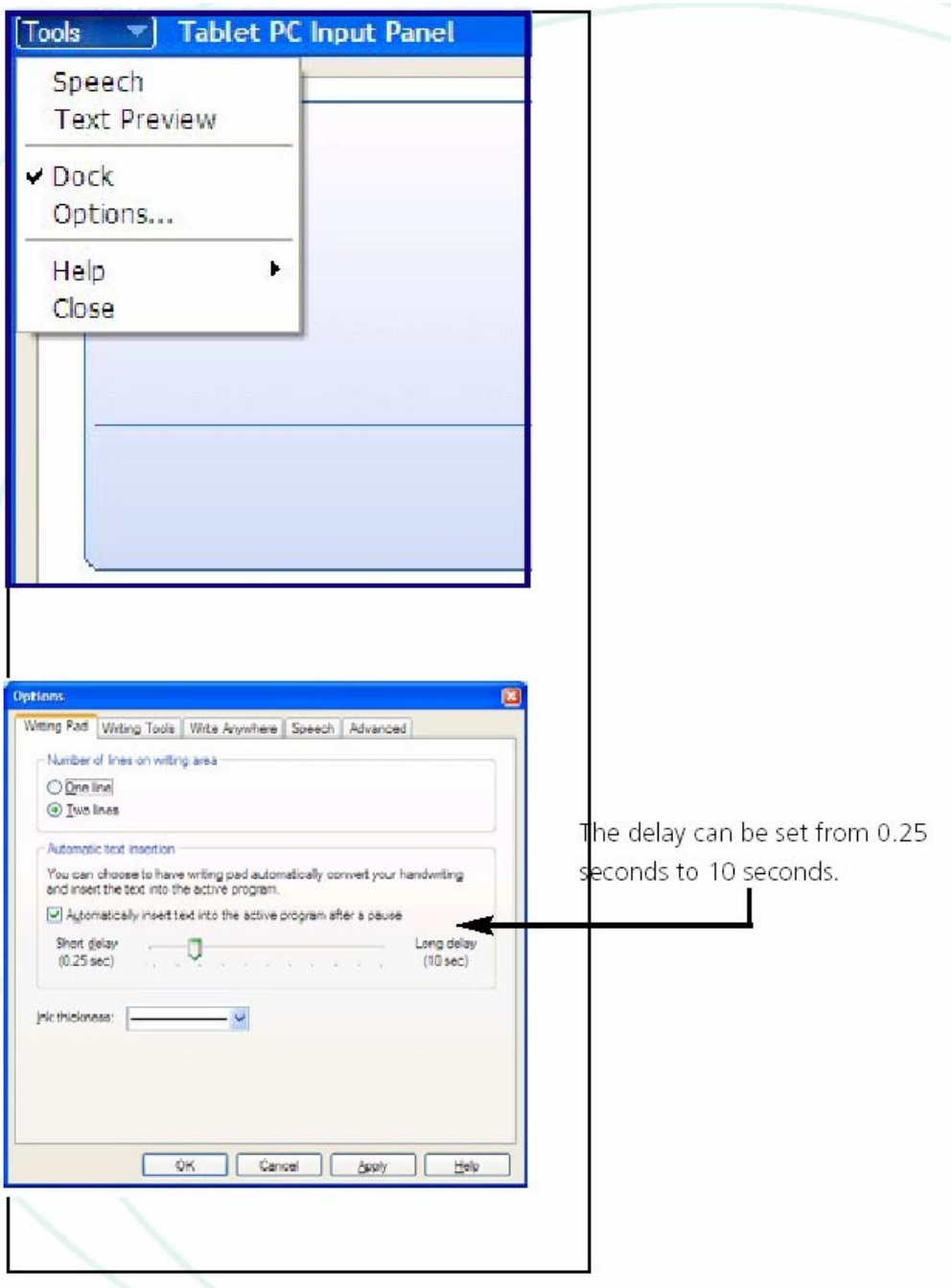
The "Ctrl" button remains highlighted until you click the next button.



Note that the "V" key is highlighted prior to being clicked to complete the paste action, and the "Ctrl" key is still active (blue).

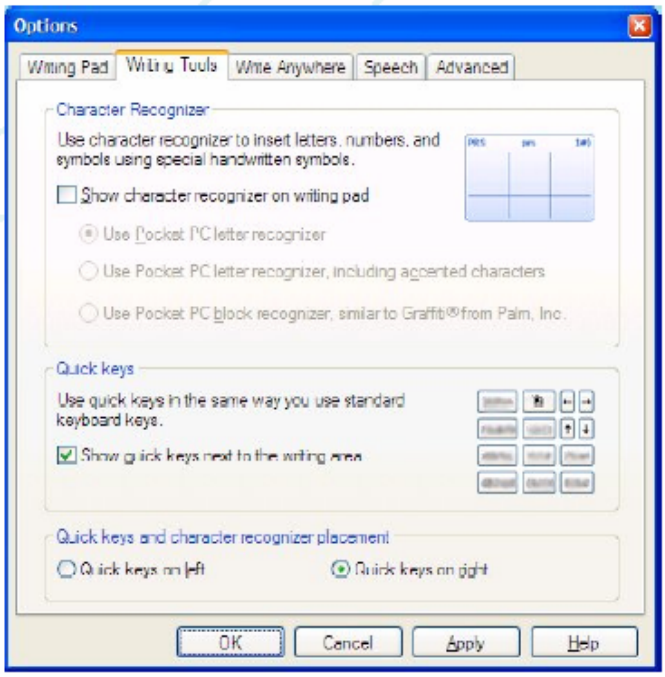
The Options Tab

The delay between finishing the writing and automatic text recognition can be set using *Tools>Options in the Input Panel.*



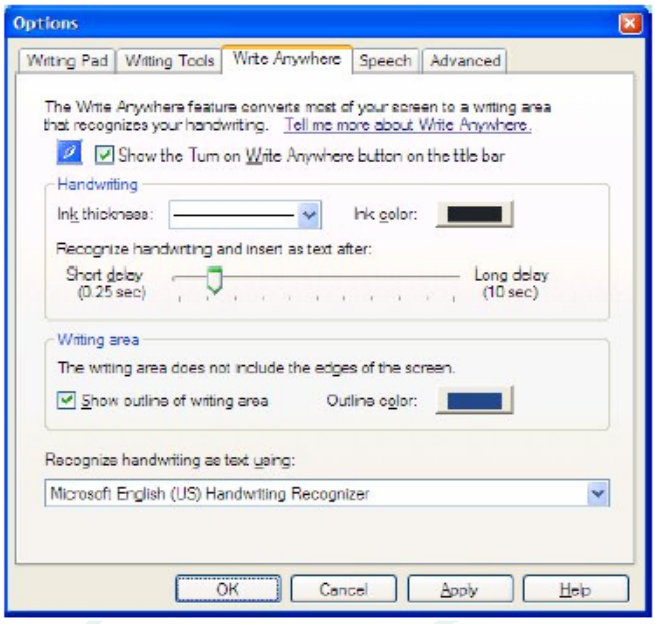
The Writing Tools Tab

The Writing Tools tab has settings for setting up the Input Panel to recognize Palm® Graffiti and Windows® Pocket PC® characters, so if you are more familiar with writing on your handheld, your new Acer TravelMate C100 will understand those characters too. You can also choose if you want the quick keys pad to be visible or not.

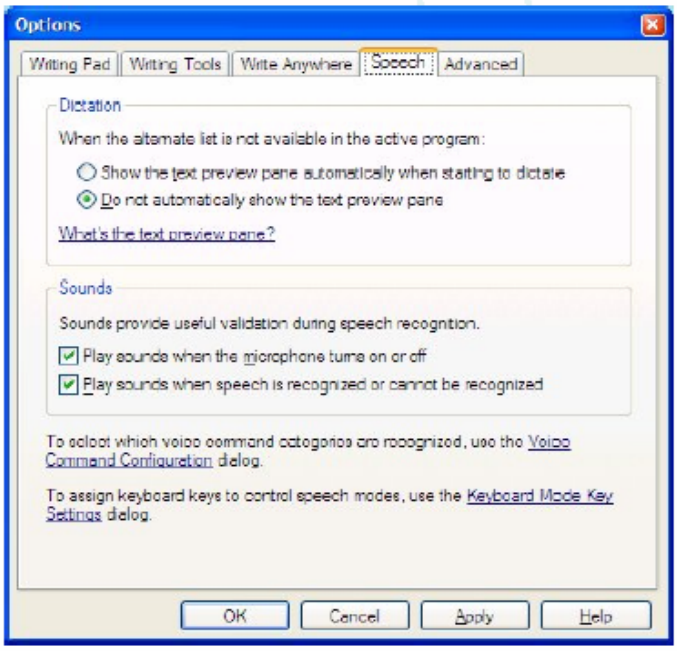


The Write Anywhere Tab

With the Write Anywhere feature, you can use most of the screen on your tablet computer as a writing area. This is especially useful for longer writing tasks.



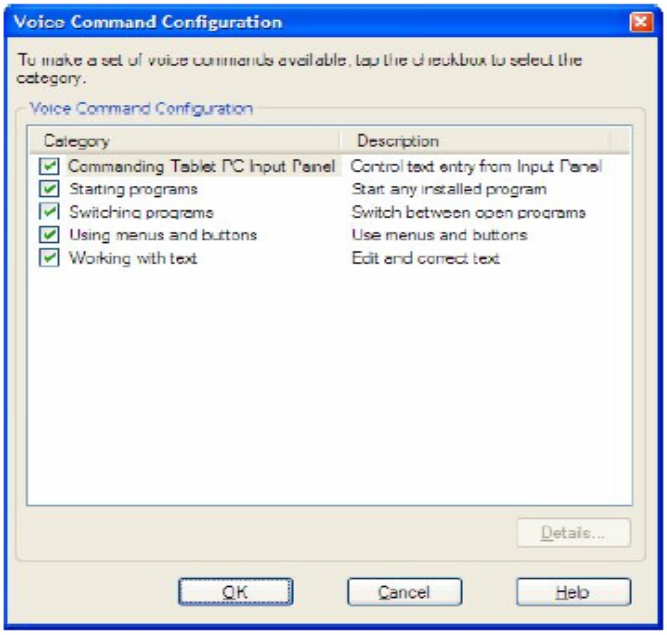
The Speech Tab



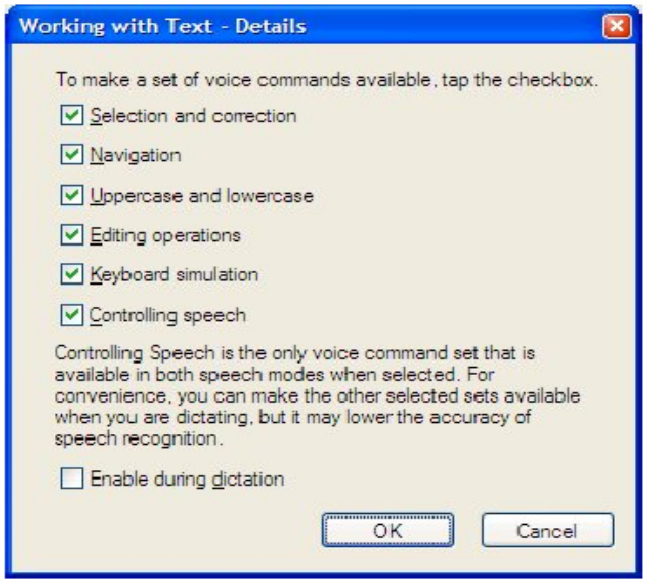
The Speech tab lets you set up how your Acer TravelMate C100 will accept spoken input. By using this tab, you can select whether the speech input application will show a text preview window or will enter the text directly into the open application. The text preview pane allows you to edit text prior to inserting it into the application.

You can also select whether your Acer TravelMate C100 will play sounds to alert you to the status of the microphone as well as whether the sounds can be recognized or not.

In addition to text input, your Acer TravelMate C100 will react to a number of predefined command phrases to perform specific functions.

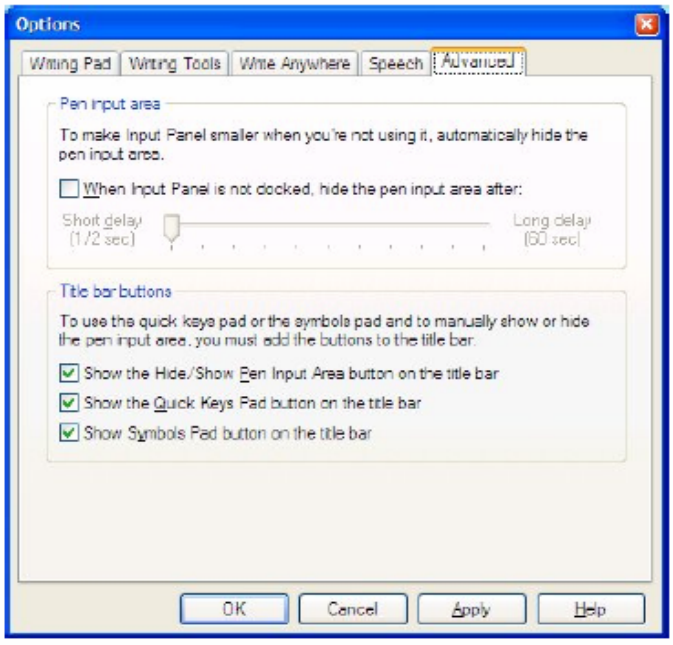


The functions fall into various categories, and are accessed by clicking the Voice Command Configuration link in the Speech tab, which will open the following window.
Select a category, and click the Details button to review the commands available in that category.



Check or uncheck the check box alongside the set of commands you wish to enable or disable.

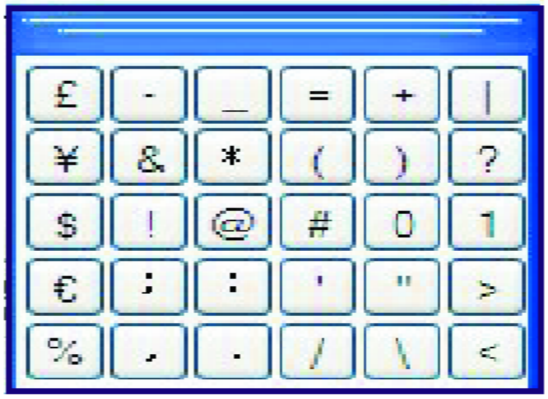
The Advanced Tab



The title bar of the Input Panel includes a number of buttons for controlling the Input Panel. You can decide if you wish to display these buttons in the title bar or not.

From left to right in the picture above, the buttons are Turn On Write Anywhere; Quick Keys Pad; Symbols Pad; Show Pen Input Area and Close.

The Symbols Pad allows you to easily insert some commonly used symbols.



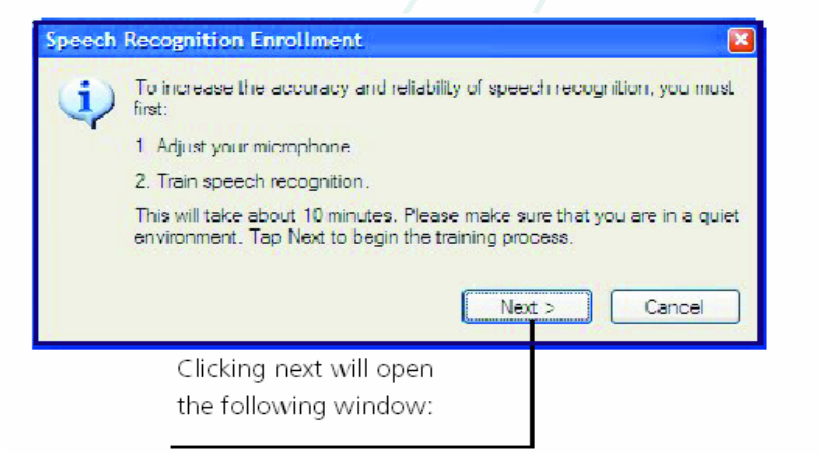
Voice Input

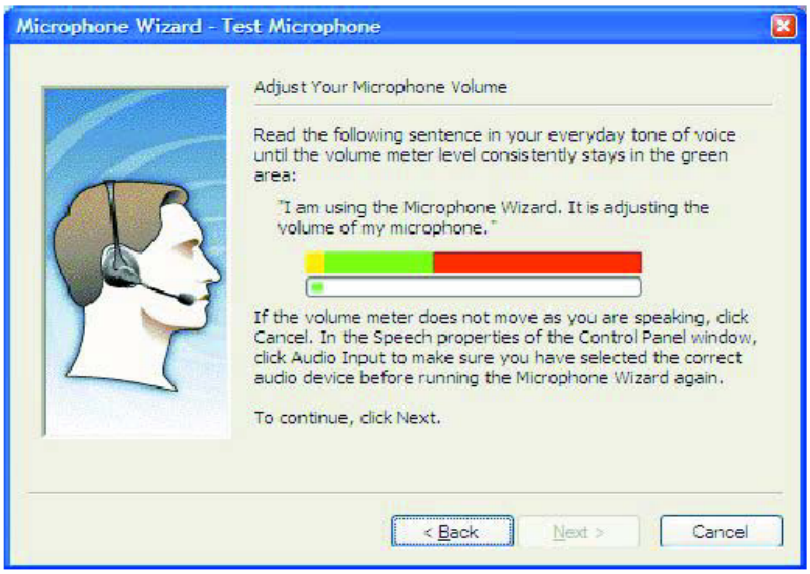
The Acer TravelMate C100 allows you to input information using natural speech. Voice input will require voice training exercises to help the computer recognize your voice. The more time spent doing the training, the better the recognition becomes.

Setting up Voice Input

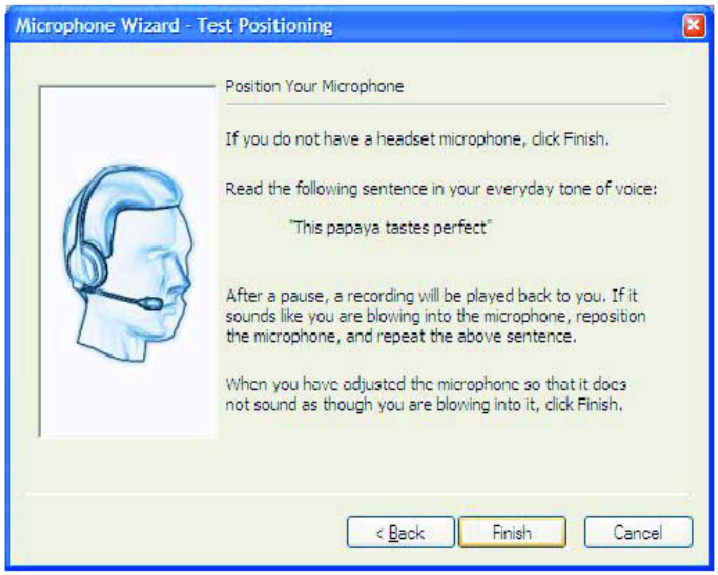
The first time you use voice input, you will need to adjust the microphone and work through a few short exercises to "teach" the voice input software, so it can recognize your manner of speaking. To start the voice input, click the Input Panel Icon, click on Speech (marked with a check sign). Click on "Start Speech".

This will open the Speech Recognition Enrollment window. These instructions are available in the **Application Manual on pages 41-44.**





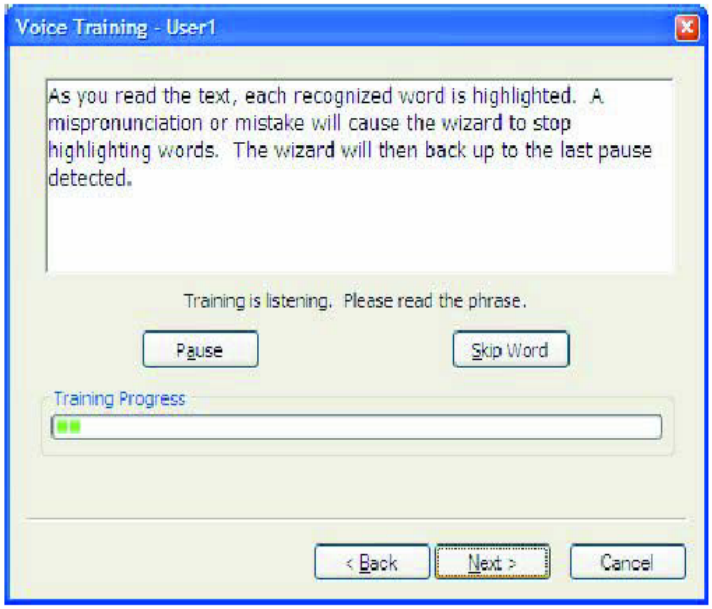
This window allows you to set up the microphone, start the training wizard, and set the microphone level. Once the microphone level has been set click Next to open the following window:



Read the sentence into your microphone. When you have finished, your sentence will be played back to you, if it sounds clear click Finish. Once you have clicked Finish, the Speech Recognition Training Wizard will open.

Indicate to your gender and age, and click next to proceed.

Make sure that the room you are in is quiet, and that the microphone is positioned correctly. Click next to begin the training.



As you read the words that appear on the screen the wizard will highlight the recognized words. If the wizard fails to recognize a word, it will return to the previous pause and require you to start from there.

Once you have finished the training, the wizard will process your speech patterns and create a voice profile for you. This profile will be used to enable voice recognition to better recognize your speech when you input data.

Additional Voice Training Exercises

To improve speech recognition on the Tablet PC there are eight passages that can be read. These passages can also be read multiple times to improve speech recognition.

Voice training is accessed from the '*Speech Tools'* drop-down menu on the '*Tablet PC Input Panel.*' In the '*Speech Tools*' drop-down menu '*Voice Training*' is selected. After this is done any one of eight passages can be selected to be read aloud to improve speech recognition. Select one of the passages and follow the directions provided.

Word Pronunciation

The word pronunciation feature allows users to record the pronunciation of a particular word for the Tablet PC to recognize. This will especially help with bridge inspection specific vocabulary.

The '*Add Pronunciation*' feature is accessed from the '*Speech Tools*' drop-down menu on the '*Tablet PC Input Panel*.' In the '*Speech Tools*' drop-down menu *'Add Pronunciation*' is selected. After this is done, the spelling of the word the user wishes to add a pronunciation for is entered into the available text panel in the '*Add Pronunciation*' window. Next the user has to select the 'Record Pronunciation' button and pronounce the word aloud. After this the computer will place the word into the dictionary that is included in the *'Add Pronunciation'* window. Users can listen to the word pronunciation by selecting the corresponding word from the dictionary. The word can be deleted if the pronunciation is unsatisfactory.

Bridge Inspection Specific Terms

- Delamination
- Scour
- Girder
- Abutment
- Riprap
- Reinforcing
- Pier
- Spall

The speech recognition may not perform well with some words or phrases due to user word pronunciation, even after the *'Add Pronunciation'* feature is used. This is a limitation that users have to be prepared for. In this event, handwriting input or keyboard input can be used to enter data.

Voice Commands

Voice input with your Acer TravelMate C100 includes the option to format and perform various functions via voice commands. Following are the commands currently supported in all voice input documents. **Full instructions regarding voice commands can be found on pages 59-65 in the Acer Application Manual available at** http://www.acersupport.com/library/tmc100tablet.pdf **or in the Acer Pocket Manual.**

Basic input commands

Say	To
"New line"	Start text on the next line.
"New paragraph"	Start a new paragraph.
"Microphone"	Turn the microphone off.
"Tab"	Press the TAB key once.
"Enter"	Press the ENTER key once.
"Spelling mode"	Spell out the next word. For example, say this before you spell out a company name or a person's name. Pause after spelling out the word to revert to normal dictation mode.
"Forcenum"	Enter a number or symbol instead of spelling it out. For example, say "Forcenum 2" to enter "2" instead of "two." Pause after saying the number or symbol to revert to normal dictation mode.
"Delete"	Delete the selected word.
"Space"	Insert a space.
"Backspace"	Delete the character to the left of the insertion point.
"Next cell"	Move the insertion point one cell to the right.
"Spell it" or "Spell that"	Spell the next word.

The Boom Microphone

The Boom Microphone is a high quality microphone that offers excellent ambient noise canceling. Instructions on the use of the Boom are included with the hardware. This microphone may take some getting used to, but should become more comfortable and perform admirably over time.

Troubleshooting the Boom

The voice recognition may not perform acceptably at times when using the boom. This could be attributed to a few different reasons. If you are having trouble with the Boom, trying one of the following solutions may remedy the problem.

1. Readjust the volume of your Microphone using the Microphone wizard.
2. Provide more voice training even if you have to repeat a lesson.
3. There is a foam cover in the box for microphone of the Boom that can be applied to the microphone to reduce unnecessary puffs of air.

Tablet PC Maintenance

The Tablet PC will require some routine care to remain operating at desired levels.

Replacing the Pen Tip

The pen tip can become scratched or rough as a result of normal wear and tear. Additional pen tips and a tool to replace the tips are provided with the Tablet PC. It will be up to users to change the tips when needed.

Cleaning the Screen

1) When folding your Acer TravelMate C100 into tablet mode. Ensure that the two-way latch is fully retracted, otherwise you may damage the latch.

2) Wipe the screen only with the cleaning cloths supplied by Acer.

3) Remember: DO NOT use any liquid cleaners on the screen. They may penetrate the electronics and permanently damage your Acer TravelMate C100.

Caring for the LCD panel

1) Do not use any input device other than the Acer EMR stylus or pen or an EMR compliant pen with your Acer TravelMate C100 's LCD input panel. Use of any non-compliant device may permanently damage your Acer TravelMate C100.

2) If you wear jewelry when working on your Acer TravelMate C100 in tablet mode, it may scratch the screen. Acer recommends that you remove all jewelry, such as watches, rings and bracelets, prior to using your PC in tablet mode.

Additional Care

Guidelines for taking care of the computer and accessories are included in the **User's Guide on pages vi-vii.** Steps for cleaning and servicing the machine are also included.

Conclusion

Users should make efforts to integrate the Tablet PC into their everyday work schedule. It is important to remember that the Tablet PC possesses the same capability that desktop PCs offer as well as additional versatility.

Appendix C: Weekly Inspector Questionnaire

Inspector: _____ **For the week of:** _____/_____/ 2003
District: _____ **Number of bridges inspected:** _____

Please circle all weather conditions experienced while inspecting bridges for the week.
Precipitation: None / Light / Moderate / Heavy **Outlook:** Cloudy / Partly Sunny / Sunny
Please comment on how weather affected your use of the Tablet PC during the week?

Please answer these questions about your use of the Tablet PC <u>at the bridge</u> for bridge inspection:

How many bridges did you inspect this week using the Tablet PC?	Bridges
Estimate how much of the inspection information you enter?	None Some Most All
Did you enter notes in the text boxes?	YES NO
Did you correct/edit the text boxes while in the field?	YES NO
Did you use the speech recognition to enter notes in text fields?	YES NO
Did you use the handwriting recognition to enter notes?	YES NO
Did you use the on-screen keyboard to enter notes?	YES NO
Did you use the electronic pocket manual?	YES NO

Please answer these questions about your use of the Tablet PC <u>in your vehicle</u> for inspection

Estimate how much of the inspection information you enter?	None Some Most All
Did you use the speech recognition to enter data?	YES NO
Did you use the handwriting recognition to enter data?	YES NO
Did you use the on-screen keyboard to enter data?	YES NO
Did you use the Table PC as a notebook computer?	YES NO
Did you use the electronic pocket manual?	YES NO

Please answer these questions about your use of <u>paper forms</u> for bridge inspection:

Estimate the amount of information recorded on paper?	None Some Most All
Indicate why you used paper forms. Circle all that apply:	Weather Don't like Pen Glare Poor Voice Rec.
Did you use the paper pocket manual?	YES NO
Where/how did you transcribe the inspection information into the database? Check one:	____In vehicle on Tablet PC ____In office on Tablet PC ____In office on desktop PC

Please answer based on using the Tablet PC for collecting bridge inspection data:

Estimate the total time per bridge for inspecting, entering data, and editing data on the Tablet PC. (exclude travel time)	Minutes
What percentage of your time (entered above) do you spend using voice recognition functions on the Tablet PC?	%
What percentage of your time (entered above) do you spend using the pen stylus and handwriting functions on the Tablet PC?	%
Rate your improvement in using the speech recognition in terms of time reduced from previous week (circle one)	10% 20% 30% 40% 50% 60%
Rate your improvement in using the pen stylus and handwriting recognition in terms of time reduced from previous week (circle one)	10% 20% 30% 40% 50% 60%

Please answer the following questions about your experience with the speech recognition data entry:

Was ambient noise during data entry a problem?	YES NO
Did the speech recognition software have to be retrained for new words or phrases?	YES NO
Was the headset comfortable enough to wear throughout the field inspection?	YES NO
Is speech recognition more convenient than handwriting recognition?	YES NO
Is speech recognition less time intensive than the handwriting recognition?	YES NO
Is speech recognition more convenient for providing detailed input into the text fields than handwriting recognition?	YES NO
Has the Tablet PC decreased inspection time overall? If yes, how much?	YES NO minutes

Please rate your agreement with the following:

(1) strongly disagree (2) somewhat disagree (3) neutral (4) somewhat agree (5) strongly agree

Inspection Process	**Value**	**Comments**
I find the Tablet PC easy to operate.		
I like the size and weight of the Tablet PC.		
I can easily handle the Tablet PC with the shoulder strap and carrying case.		
I like the speech recognition data input.		
I find the headset for speech recognition comfortable		
I like the pen stylus (handwriting) input.		
I can clearly read the screen in outdoor lighting.		
The Tablet PC screen size is large enough for viewing the inspection forms.		
The Table PC's battery life is adequate.		
The Tablet PC is durable enough for field use (able to survive 2 years of field use).		
I have used this Tablet PC for other office or field jobs.		
I would use this Tablet PC for other office or field jobs.		

Please add your comments: